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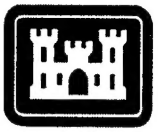

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Upper Mississippi River Lock Filling and Emptying System

Hydraulic Model Investigation

Jose E. Sanchez, Mario J. Sanchez,
and John E. Hite, Jr.

September 2002

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September 2002

Upper Mississippi River Lock Filling and Emptying System

Hydraulic Model Investigation

by Jose E. Sanchez, Mario J. Sanchez, John E. Hite, Jr.

Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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Preface

The model investigation reported herein was authorized by Headquarters, U.S. Army Corps of Engineers at the request of the U.S. Army Engineer District, Rock Island (MVR) on 21 December 1999. The model experiments were performed during the period July 2000 to October 2000 by personnel of the Coastal and Hydraulics Laboratory (CHL) of the U.S. Army Engineer Research and Development Center (ERDC), (formerly the Waterways Experiment Station) under the general supervision of Mr. Thomas W. Richardson, Director of CHL; and Mr. Thomas J. Pokrefke, former Acting Assistant Director, CHL.

The experimental program was led by Messrs. J. E. Sanchez and M. J. Sanchez under the supervision of Dr. J. E. Hite, Jr., leader, Locks and Conduits Group, and Dr. S. K. Knight, Chief, Navigation Branch, CHL. Model construction was completed by Messrs. J. A. Lyons and K. Raner of the Model Shop, Department of Public Works (DPW), ERDC, under the general supervision of Mr. J. Schultz, Chief of the Model Shop, DPW. Data acquisition and remote control equipment were installed and maintained by Messrs. S. W. Guy and T. Nicely, Information Technology Laboratory (ITL), ERDC. Data acquisition software was developed by Dr. B. W. McCleave, ITL. The report was written by Messrs. J. E. Sanchez and M. J. Sanchez and Dr. Hite. Ms. Kathy Miller of the Navigation Branch, CHL, helped in the preparation of the report.

During the course of the model study, Messrs. Kevin Landwehr, Marv Martens, and Roger Perk MVR, Mr. Billy Arthur, MVS, and Mr. Bob Occhipinti, MVD, visited ERDC to observe model operation, review experiment results, and discuss model results.

At the time of publication of this report Dr. James R. Houston was Director of ERDC and COL John W. Morris III, EN, was Commander and Executive Director.

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1 Introduction

Background

Navigation improvements including lock extensions are being investigated for several existing projects on the Upper Mississippi River (UMR). Without improvements, the potential for significant traffic delays on the system will occur resulting in significant economic losses to the nation. This is not a final design; but an initial evaluation of a proposed filling and emptying (F and E) system for an extended lock. The model investigation reported herein is just one part of a larger system study conducted to establish an array of feasible navigation improvement measures, their associated costs, and their benefits in terms of improving the navigation conditions and lock performance.

Conceptual lock designs that are feasible from an engineering perspective have been investigated. The lowest first cost for these designs was determined to be extending the existing 182.8-m (600-ft) lock to 365.6 m (1,200 ft). However, the risks and uncertainties in cost, performance, and construction techniques of building a lock extension are greater than building a lock away from tow traffic. Additional lock performance data were required to fully evaluate the lock extension design.

The proper performance of the filling and emptying (F and E) system and appurtenances are crucial to the success of these improvements. A laboratory model of the F and E system is typically used to ensure the F and E design functions as needed.

Prototypes

This study focused on existing locks 22 and 25 located on the Upper Mississippi River. Lock No. 22 is located in the Rock Island District at river mile 301.1 near Saverton, MO (Figure 1). Lock No. 25 is located in the St. Louis District at river mile 241.4 near Winfield, MO (Figure 1). Each project contains a gated dam section for river regulation, an overflow weir section, and a lock chamber. The locks are 33.53 m by 182.88 m (110 ft by 600 ft) and are located on the right descending bank of the river. The maximum lift for lock No. 22 is 3.20 m (10.5 ft) and 4.57 m (15 ft) for lock No. 25. The existing F and E systems for the locks are the sidewall culvert type (also referred to as a side port F and E system) with intakes located in the upper approach walls and outlets located in the lower approach walls. The existing riverward intake and outlet at each

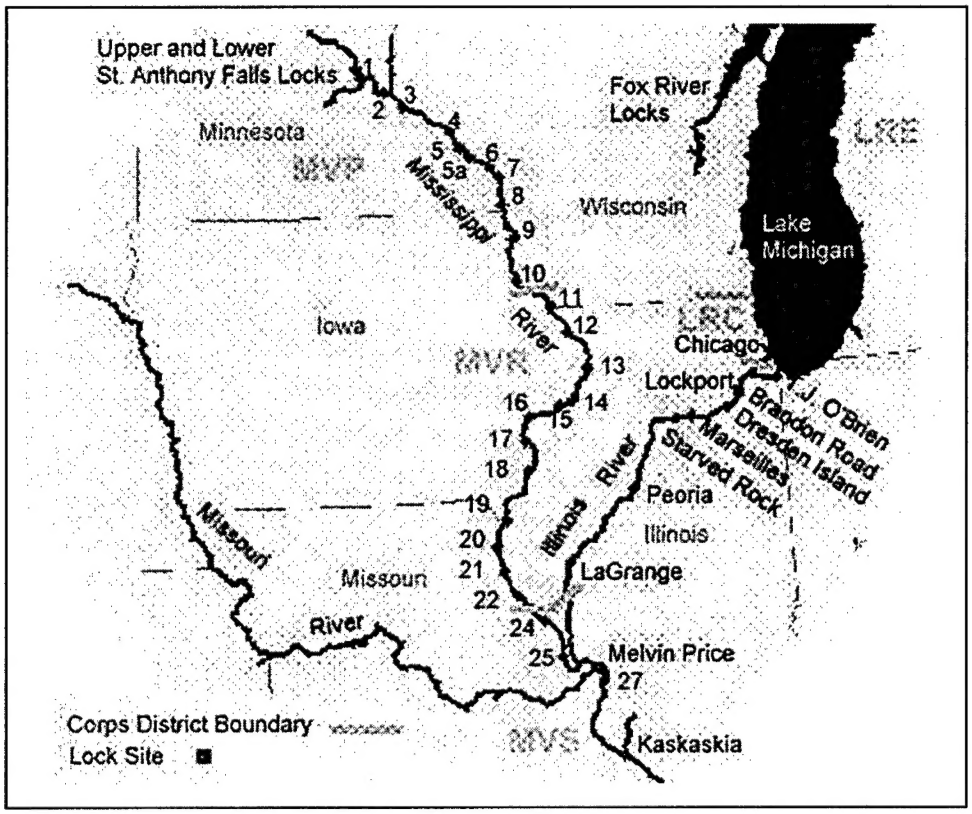

Figure 1. Location of lock and dam No.22 and No. 25

project were designed to draw and discharge, respectively from each side of the approach wall.

Existing lock No. 25 F and E details

A schematic of the F and E system for lock No. 25 is shown in Plate 1. The culverts for lock No. 25 transition from a 3.81-m by 3.81-m (12.5-ft by 12.5-ft) rectangular section to a 4.27-m (14-ft) diam circular section just downstream from the filling valves. The river wall culvert transitions from circular back to rectangular between the 16th and 17th port and remains rectangular to the outlet. The land wall culvert is circular throughout the length where the sidewall ports are located and transitions back to circular just upstream from the emptying valve. The culvert is rectangular between the intakes and the filling valve wells and between the emptying valve wells and the outlets. There are 20 ports spaced along the length of the culvert sections. Each port is 0.91 m (3 ft) high by 1.22 m (4 ft) wide. The center of the first port is located 48.77 m (160 ft) from the upper pintle and the center of the last port is 30.48 m (100 ft) from the lower pintle. The first eight ports are spaced 3.04 m (10 ft) center to center; the next four ports are spaced 6.10 m (20 ft) center to center; the next three ports are spaced 7.62 m (25 ft) center to center; the next two ports are spaced 9.14 m (30 ft) center to center; and the last three ports are spaced 10.67 m (35 ft) center to center. The bottom of the ports is 0.48 m (1.5 ft) above the floor of the lock chamber. Unlike more modern side port designs, these ports are located directly across from one

another as opposed to staggering the ports. Tainter valves are used to fill and empty the lock chamber.

Existing lock No. 22 F and E details

The culverts for Lock No. 22 are 3.81 m by 3.81 m (12.5 ft by 12.5 ft) rectangular shaped throughout the system. There are 20 ports spaced at 6.28 m (20 ft) center to center along the land wall and 6.28 m (20 ft) center to center along the river wall. Each port is 0.91 m (3 ft) high by 1.22 m (4 ft) wide. The center of the first port on the river wall is located 45.72 m (150 ft) from the upper pintle. The center of the first port on the land wall is located 24.38 m (80 ft) from the upper pintle. The bottom of the ports is 0.48 m (1.5 ft) above the floor of the lock chamber.

Proposed lock extension

As previously mentioned, the lowest combined first cost and impacts to navigation during construction for developing a 365.6-m (1,200-ft) lock at UMR projects is to extend the existing 182.8-m (600-ft) lock to 365.6 m (1,200 ft). This design is referred to as the 2R lock design in the District's correspondence. The initial design lock extension for this study is shown in Plate 2. A new lock wall was added on the landside from the lower pintle of the existing lock downstream for 185.92 m (610 ft) to the new lower pintle. A new coffer cell type lock wall initially designed with 10 emptying valves and ports was added on to the existing riverside lock wall. The vertical lift valves were located inside the emptying ports. Each port was 3.05 m wide by 1.22 m high (10 ft wide by 4 ft high). Due to the addition of the new lock walls, all existing emptying capacity is lost from the landside of the lock and half of the outlet area is lost from the riverside of the lock. The existing emptying tainter valve remains in place and operable on the river wall. The existing filling system was not affected by the lock extension.

The performance concept for this design was to accept a slower filling time since the existing filling system was not supplemented and increase the emptying capacity with a supplemental emptying system to speed up the emptying times. Since three-fourths of the existing emptying system could not be used due to the addition of the new lock walls, a significant size supplemental emptying system was needed to gain benefits.

Purpose and Scope

Due to the uniqueness of the proposed lock extension design and the need to determine the lock performance data as accurately as possible for economical reasons, a laboratory model was considered necessary.

The specific objectives of the study were to determine the following:

a. Filling and emptying times for various valve speeds at typical lifts for lock No. 22 and lock No. 25 (up to 4.57 m (15 ft)).

b. Emptying times with these typical lifts for emptying valve operations with various combinations of emptying valves in operations.

c. Hawser forces exerted on barges moored in the lock chamber.

d. Overall system performance.

A laboratory model was used to evaluate the performance of the filling and emptying system. Model studies of lock filling and emptying systems designed for barge traffic have targeted maximum hawser forces of 44.48 kN (5 tons) as a design objective. System design and operation for new projects are optimized such that a full tow at design draft produce hawser forces of 44.48 kN (5 tons) or less during lock operations at the design pool conditions. This limiting maximum hawser force guidance is provided in paragraph 8-6 of Engineer Manual 1110-2-2602 "Planning and design of navigation locks," paragraph E-2 of EM 1110-2-1604 "Hydraulic design of navigation locks" and also in the discussion of permissible filling times in paragraph D-15 of EM 1110-2-1604. Davis (1989) summarizes the findings of physical model studies

> "In working with models to determine hawser stresses, it must be noted that when a hawser stress of only 5 tons is achieved in a model it does not necessarily follow that the hawser stress on the prototype lock will be no greater than the value measured in the model. On a performance basis it has been found that when the model hawser stress is no greater than 5 tons, the prototype lock will perform very well and no surging or severe turbulence will occur."

2 Physical Model

Description

A 1:25-scale model was designed to determine the range of lock performance for both lock No. 22 and No. 25. The F and E systems for these projects are slightly different from one another. Lock No. 25 contains a circular culvert in the ported section and the ports were spaced irregularly. Lock No. 22 has a rectangular culvert with more evenly spaced ports. These differences primarily affect filling operations. More energy losses would occur with the lock No. 25 system. Since the focus of this study was to determine emptying performance for multiple options of emptying gates, it was decided to use the side port system for lock No. 25 since the filling times would be the slowest anticipated. Also, lock No. 25 configuration is more unbalanced than lock No. 22 configuration, which would lead to greater longitudinal hawsers and therefore longer valve (and filling) times. The lock chamber was 33.53 m wide (110 ft wide) and 390.12 m (1,280 ft) from pintle to pintle. The model reproduced the entire filling and emptying system, which included intakes, filling and emptying valves, culverts, the sidewall ports, and the outlet. The upper and lower approaches were reproduced to the extent that proper flow conditions occurred in these areas. The intakes, filling and emptying culverts, and the discharge outlet were constructed of plastic and the filling and emptying valves were built from brass. A model layout is shown in Plate 3 and photographs of the model are provided in Figures 2-5.

Details of the filling and emptying system are provided in Plates 2 and 4. One intake was located in the right guide wall (right intake) and consisted of six ports 2.43 m high by 1.52 m wide (8 ft high by 5 ft wide) with an intake port-to-culvert area ratio at the filling valve well of 1.54. The other intake (left intake) was located in the left guard wall and consisted of three ports 2.43 m high by 1.52 m wide (8 ft high by 5 ft wide) located on each side of the guard wall with a intake port-to-culvert area ratio at the filling valve well of 1.54. The flow into the intakes feed into rectangular culverts 3.81 m by 3.81 m (12.5 ft by 12.5 ft) through the filling valve wells and then transition to circular culverts. The left filling valve was located further downstream than the right valve. When the project was initially constructed, there were plans to locate a smaller lock riverward of the existing lock. The left filling valve for the existing lock had to be moved further downstream to avoid the miter recess for the proposed smaller lock. The circular culvert in the river wall transitions to rectangular between the 16th and 17th ports and remains this shape to the outlet. This culvert transition

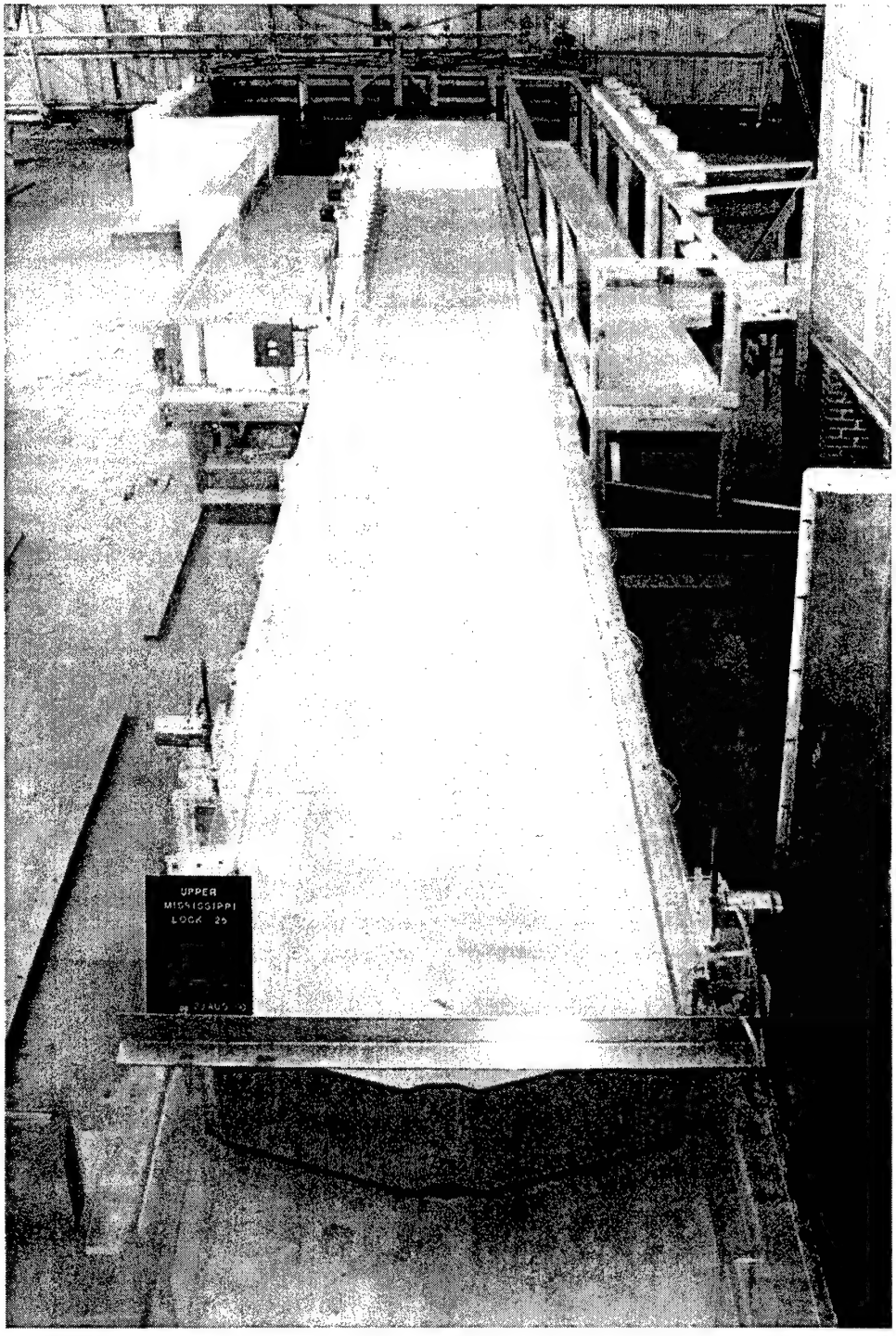

Figure 2. 1:25-scale model of Upper Mississippi filling and emptying system

Figure 3. Close-up of discharge ports on river wall extension

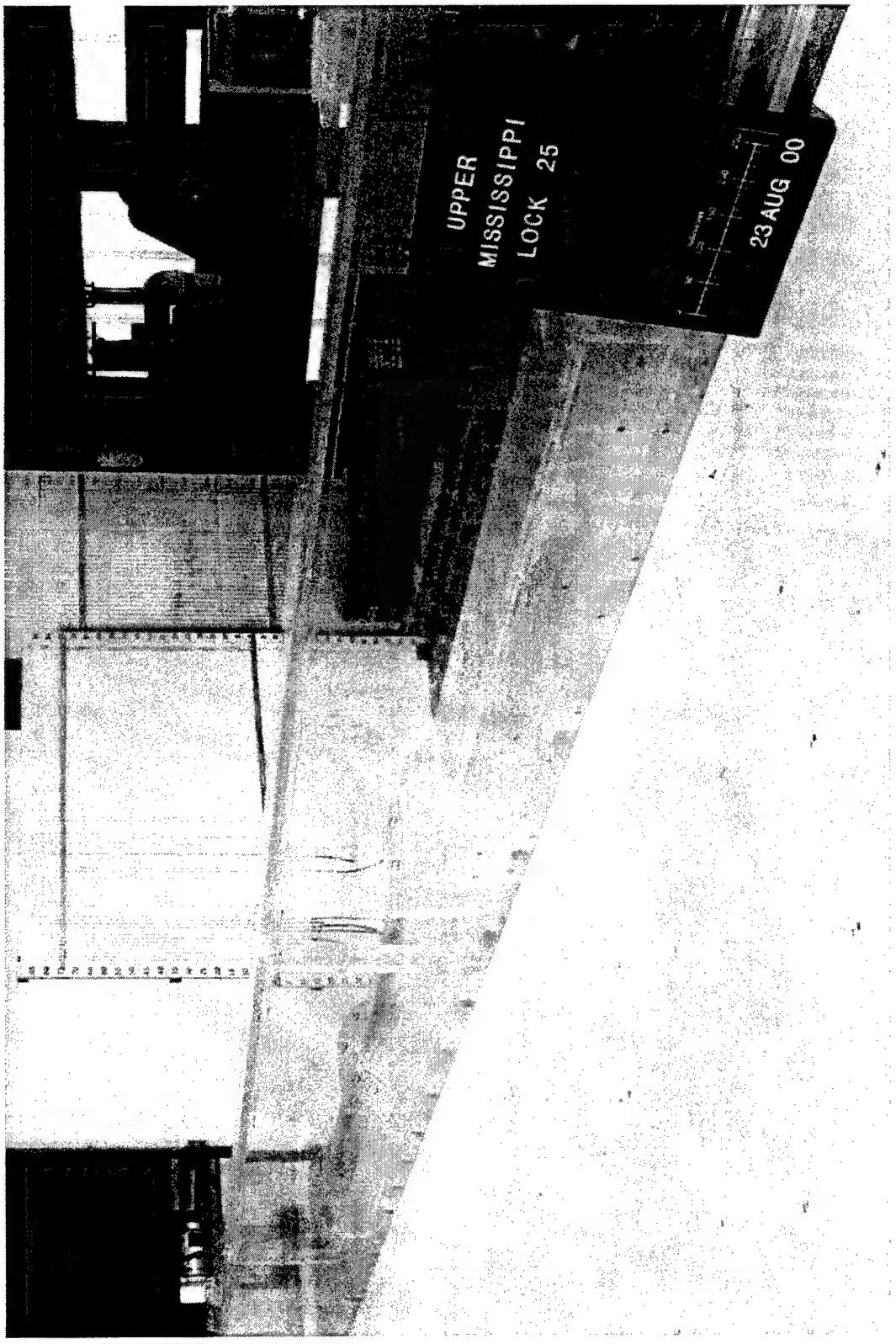

Figure 4. Close-up view of sidewall ports on river wall

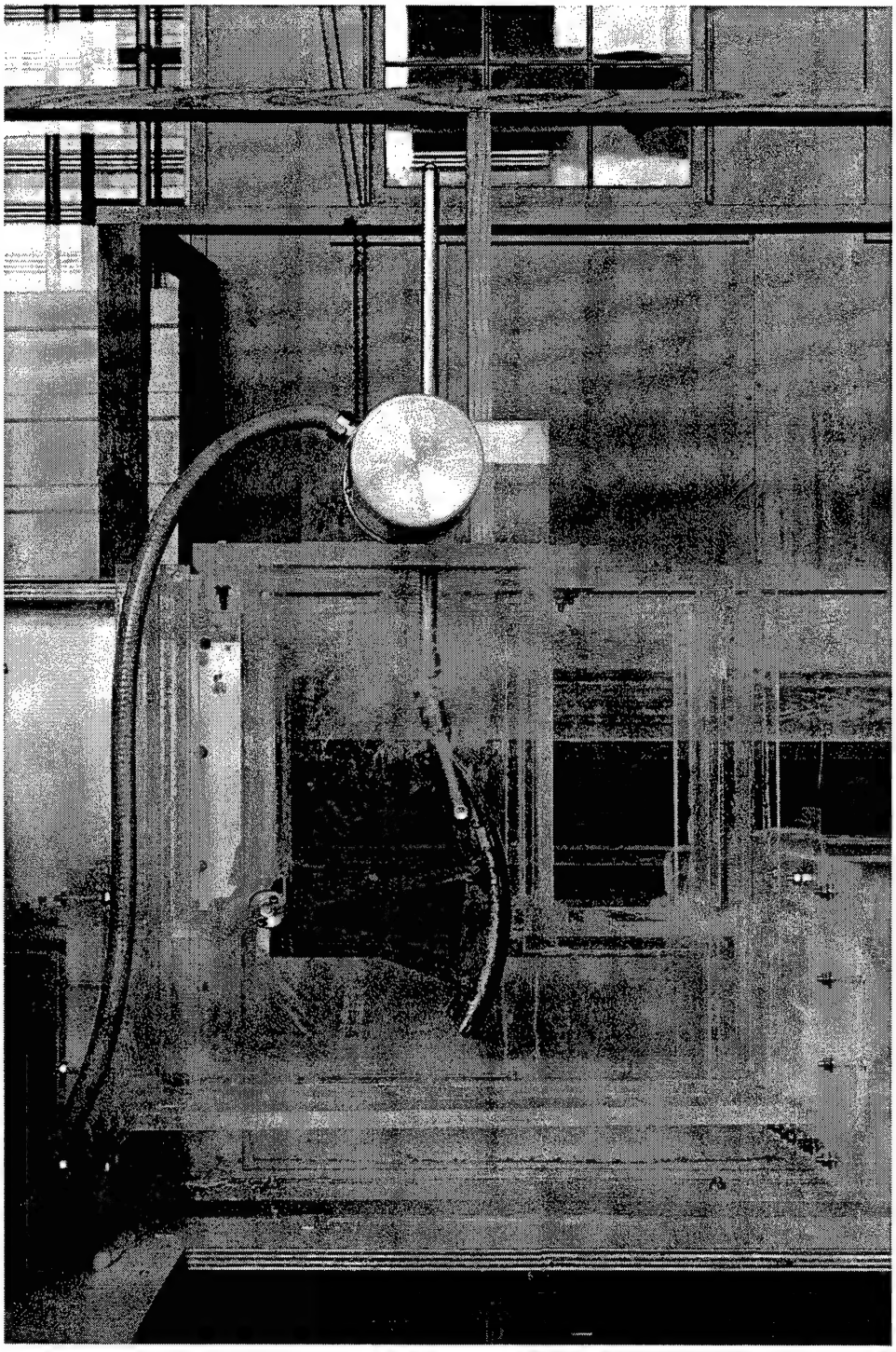

Figure 5. Riverside empty valve (tainter)

was necessary to avoid the lower miter recess of the proposed smaller lock. The land wall culvert was circular throughout the section of sidewall ports and transitioned to rectangular just upstream from the emptying valves. Twenty sidewall ports were spaced along the length of the sections. Each port was 0.91 m (3 ft) high by 1.22 m (4 ft) wide. The center of the first port was located 48.77 m (160 ft) from the upper pintle and the center of the last port was 30.48 m 100 ft from the lower pintle. The first eight ports are spaced 3.05 m (10 ft) center to center; the next four ports are spaced 6.10 m (20 ft) center to center; the next three ports are spaced 7.62 m (25 ft) center to center; the next two ports are spaced 9.14 m (30 ft) center to center; and the last three ports are spaced 10.67 m (35 ft) center to center. The port-to-culvert area ratio throughout the sidewall port section of the culvert was 1.56. The land wall culvert did not have an emptying valve. The river wall culvert contained an emptying valve located approximately 182.87 m (600 ft) downstream from the upper pintle. The first port of the outlet was located 6.10 m (20 ft) downstream from the lower pintle. The outlet contained three ports 1.52 m wide by 1.83 m high (5 ft wide by 6 ft high) spaced 2.74 m (9 ft) center to center which discharge on the riverside of the wall. The outlet port-to-culvert area ratio at the emptying valve for this culvert was 0.58. The river wall in the extended portion of the lock chamber contained 10 discharge ports each 3.05 m wide by 1.22 m high (10 ft wide by 4 ft high) spaced 12.07 m (39.6 ft) center to center. The center of the first port was located 33.71 m (110.6 ft) downstream from the lower pintle. Vertical lift valves were located at the center of each discharge port. These ports provided 37.16 m^2 (400 ft^2) of discharge area in addition to the area in the upper river wall culvert.

Appurtenances and Instrumentation

Water was supplied to the model through a circulating system. The upper and lower pools were maintained at near constant elevations during the filling and emptying operations using constant head skimming weirs in the model headbay and tailbay. During a typical filling operation, excess flow was allowed to drain over the weirs at the beginning of the fill operation and minimal flow over the weir was maintained at the peak discharge thereby minimizing the drawdown in the upper reservoir. The opposite of this operation was performed during lock emptying. Upper and lower pool elevations were set to the desired level by adjusting the skimming weirs and reading piezometers placed in calm areas of the upper and lower pools. Water-surface elevations inside the chamber were determined from electronic pressure cells located in the middle and on each end of the lock chamber. Dye and confetti were used to study subsurface and surface current directions.

An automated data acquisition and control program, Lock Control, written by Dr. Barry McCleave of the ERDC Information Technology Laboratory was used to control valve operations and collect pressure and strain gauge data. Up to 19 data channels were used, 12 for control of the filling and emptying valves, four for pressure data, and three for collecting strain gauge information. The data were usually collected at a sampling rate of 50 Hz. Some of the hawser force and lock filling and emptying data were collected at 10 Hz. These data were then processed using a computer program written by Dr. Richard Stockstill of the ERDC Coastal and Hydraulics Laboratory. The processed data were used to

determine lock filling and emptying times, longitudinal and transverse hawser forces, and pressures downstream from the filling and emptying valves.

A hawser-pull (force links) device used for measuring the longitudinal and transverse forces acting on a tow in the lock chamber during filling and emptying operations is shown in Figure 6.

Three such devices were used: one measured longitudinal forces and the other two measured transverse forces on the downstream and upstream ends of the tow, respectively. These links were machined from aluminum and had SR-4 strain gauges cemented to the inner and outer edges. When the device was mounted on the tow, one end of the link was pin-connected to the tow while the other end was engaged to a fixed vertical rod. While connected to the tow, the link was free to move up and down with changes in the water surface in the lock. Any horizontal motion of the tow caused the links to deform and vary the signal, which was recorded with a personal computer using an analog-to-digital converter. The links were calibrated by inducing deflection with known weights. Instantaneous pressure and strain gauge data were recorded digitally with a personal computer.

Similitude Considerations

Kinematic similitude

Kinematic similarity is an appropriate method of modeling free-surface flows in which the viscous stresses are negligible. Kinematic similitude requires that the ratio of inertial forces ($\rho V^2 L^2$) to gravitational forces ($\rho g L^3$) in the model are equal to those of the prototype. Here, ρ is the fluid density, V is the fluid velocity, L is a characteristic length, and g is the acceleration due to gravity. This ratio is generally expressed as the Froude number, N_F,

$$N_F = \frac{V}{\sqrt{gL}}$$

where L, the characteristic length, is usually taken as the flow depth in open-channel flow.

The Froude number can be viewed in terms of the flow characteristics. Because a surface disturbance travels at celerity of a gravity wave, $(gh)^{1/2}$, where h is the flow depth, it is seen that the Froude number describes the ratio of advection speed to the gravity wave celerity. Evaluation of the lock chamber performance primarily concerns modeling of hawser forces on moored barges during filling and emptying operations. These hawser forces are generated primarily by slopes in the lock chamber water surface. The tow's bow-to-stern water-surface differentials are the result of long period seiches or oscillations in the lock chamber. Seiching is gravity waves traveling in the longitudinal direction from the upper miter gates to the lower miter gates. Equating Froude numbers in the model and prototype is an appropriate means of modeling the lock chamber.

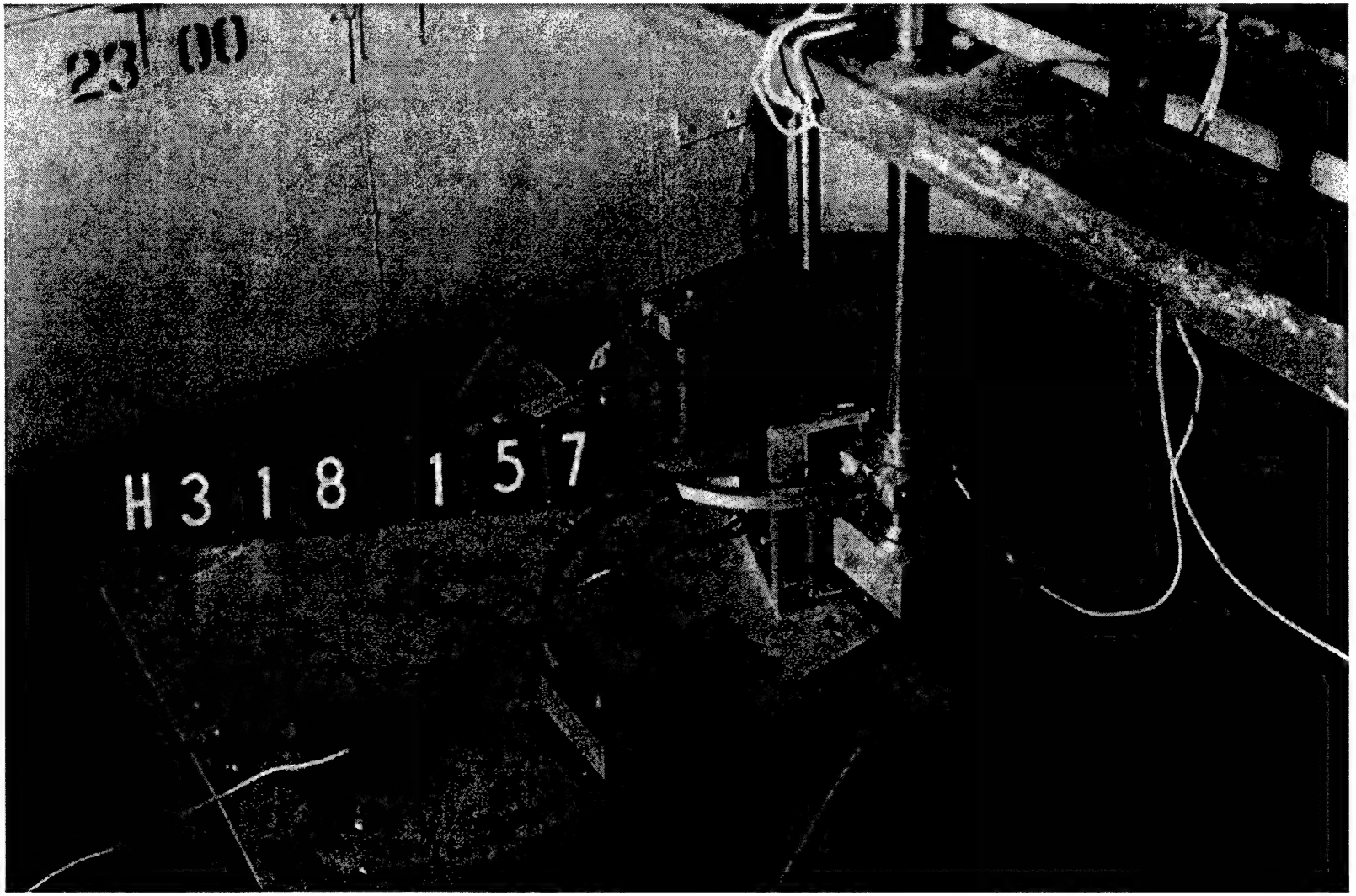

Figure 6. Hawser-pull (force links) measuring device

Dynamic similitude

Modeling of forces is a significant purpose of the laboratory investigation. Appropriate scaling of viscous forces requires the model be dynamically similar to the prototype. Dynamic similarity is accomplished when the ratios of the inertia forces to viscous forces (μVL) of the model and prototype are equal. Here, μ is the fluid viscosity. This ratio of inertia to viscous forces is usually expressed as the Reynolds number

$$N_R = \frac{VL}{\nu}$$

where ν is the kinematic viscosity of the fluid ($\nu = \mu / \rho$) and the pipe diameter is usually chosen as the characteristic length, L, in pressure flow analysis.

Similitude for lock models

Complete similitude in a laboratory model is attained when geometric, kinematic, and dynamic similitudes are satisfied. Physical models of hydraulic structures with both internal flow (pressure flow) and external flow (free surface) typically are scaled using kinematic (Froudian) similitude at a large enough scale so that the viscous effects in the scaled model can be neglected. More than 50 model and 10 prototype studies of lock filling and emptying systems have been investigated (Pickett and Neilson 1988). The majority of these physical model studies used a scale of 1 to 25 (model to prototype). Lock model velocities scaled using kinematic similitude (model Froude number equal to prototype Froude number) in a 1:25-scale model have maximum Reynolds numbers at peak discharges on the order of 10^5 yet the corresponding prototype values are on the order of 10^7.

Boundary friction losses in lock culverts are empirically described using the smooth- pipe curve of the Darcy-Weisbach friction factor where the head loss is expressed as

$$H_f = f \frac{L}{D} \frac{V^2}{2g}$$

where H_f is the head loss due to boundary friction, f is the Darcy-Weisbach friction factor, L is the culvert length, and D is the culvert diameter. The Darcy-Weisbach friction factor for turbulent flow in smooth pipes is given in an implicit form (Vennard and Street 1982)

$$\frac{1}{\sqrt{f}} = 2.0 \log\left(N_R \sqrt{f}\right) - 0.8$$

Because f decreases with increasing N_R, the model is hydraulically "too rough". The scaled friction losses in the model will be larger than those experienced by

the prototype structure. Consequently, the scaled velocities (and discharges) in the model will be less and the scaled pressures within the culverts will be higher than those of the prototype. Low pressures were not a major concern with this design; however, the lower discharges would in turn result in longer filling and emptying times in the model than the prototype will experience. Prototype filling and emptying times for similar designs will be less than those measured in a 1:25-scale lock model.

Modeling of lock filling and emptying systems is not entirely quantitative. The system is composed of pressure flow conduits and open-channel components. Further complicating matters, the flow is unsteady. Discharges (therefore N_I and N_R) vary from no flow at the beginning of an operation to peak flows within a few minutes and then return to no flow at the end of the cycle. Fortunately though, engineers now have about 50 years of experience in conducting large-scale models and subsequently studying the corresponding prototype performance. This study used a 1:25-scale Froudian model in which the viscous differences were small and could be estimated based on previously reported model-to-prototype comparisons. Setting the model and prototype Froude numbers equal results in the following relations between the dimensions and hydraulic quantities:

Characteristic	Dimension[1]	Scale Relation Model :Prototype
Length	$L_r = L$	1:25
Pressure	$P_r = L_r$	1:25
Area	$A_r = L_r^2$	1:625
Velocity	$V_r = L_r^{1/2}$	1:5
Discharge	$Q_r = L_r^{5/2}$	1:3, 125
Time	$T_r = L_r^{1/2}$	1:5
Force	$F_r = L_r^3$	1:15,625
[1]Dimensions are in terms of length.		

These relations were used to transfer model data to prototype equivalents and vice versa.

Experimental Procedures

Evaluation of the various elements of the lock system was based on data obtained during typical filling and emptying operations. Performance was based primarily on hawser forces on tows in lockage, roughness of the water surface, pressures, and time required for filling and emptying.

3 Model Experiments and Results

Filling Operations

4.57-m (15-ft) lift

Initial model experiments were performed to evaluate the performance of the existing filling system with a lift of 4.57 m (15 ft) and a sidewall port submergence of 3.35 m (11 ft). The original design is shown in Plate 2. The sidewall port submergence is defined as the distance from the lower pool to the top of the sidewall port. At lock No. 25, these lift and submergence conditions represent an upper pool el 434 and a lower pool el 419.[1]

These will be the conditions for the 4.57-m (15-ft) lift unless otherwise stated. Plate 5 shows typical time-histories of water surface and hawser forces during filling with a 4.57-m (15-ft) lift and 5-min filling valve. The maximum downstream longitudinal hawser was -177.04 kN (-19.9 tons) and occurred between 1 and 2 min into the filling operation. The negative sign indicates the longitudinal hawser force is in the downstream direction. This exceeds the 44.48-kN (5-ton) target for acceptable chamber operations. The time-history of longitudinal hawser force illustrates the conditions that exist with an F and E system that only fills in the upper half of the lock chamber. The longitudinal hawser forces remain in the downstream direction until 5 min into filling. The maximum upstream transverse hawser forces measured during filling with a 4.57-m (15-ft) lift and 5-min valve were -32.92 kN (-3.7 tons) to the left side (looking downstream) of the chamber and 2.7 tons to the right side of the chamber. The negative sign represents a transverse hawser force that moves the barges to the left side of the chamber. A positive transverse hawser would move the barges to the right side of the chamber. The maximum downstream transverse hawser forces measured during filling with a 4.57-m (15-ft) lift and 5-min valve were -29.36 kN (-3.3 tons) to the left side of the chamber and 28.47 kN (3.2 tons) to the right side of the chamber. The transverse hawser forces did not exceed the 44.48-kN (5-ton) limit with the 4.57-m (15-ft) lift and 5-min filling valve.

[1] All elevations (el) cited herein are in feet referenced to the National Geodetic Vertical Datum (to convert feet to meters, multiply number of feet by 0.3048).

To determine the filling time required to maintain 44.48-kN (5-ton) hawser forces or less with a 4.57-m (15-ft) lift, experiments were conducted with filling valve operations of 5, 15, 20, and 23 min. The results from these experiments are shown in Plate 6. The hawser forces shown are the average maximum from multiple experiments with identical test conditions (lift and valve operation). The filling time required to maintain hawser forces of 44.48 kN (5 tons) or less was 23.1 min. This filling time resulted from a 23.0-min valve operation (Plate 7).

3.20-m (10.5-ft) lift

Experiments were also conducted to determine the performance of the filling system with an upper pool el 429.5 and a lower pool el 419 (corresponding to the maximum lift at lock and dam No. 22). Plate 8 shows typical time-histories of water surface and hawser forces during filling with a 3.2-m (10.5-ft) lift and 5-min filling valve. The maximum downstream longitudinal hawser was -144.12 kN (-16.2 tons) and occurred between 1 and 2 min into the filling operation. The maximum upstream transverse hawser forces measured during filling with a 3.2-m (10.5-ft) lift and 5-min valve were -23.13 kN (-2.6 tons) to the left side of the chamber and 21.35 kN (2.4 tons) to the right side of the chamber. The maximum downstream transverse hawser forces measured during filling with a 3.2-m (10.5-ft) lift and 5-min valve were -24.91 kN (-2.8 tons) to the left side of the chamber and 20.46 kN (2.3 tons) to the right side of the chamber. The transverse hawser forces did not exceed the 44.48-kN (5-ton) limit with the 3.2-m (10.5-ft) lift and 5-min filling valve.

To determine the filling time required to maintain 44.48-kN (5-ton) hawser forces or less with a 3.2-m (10.5-ft) lift, experiments were conducted with filling valve operations of 5, 15, and 20 min. The results from these experiments are shown in Plate 9. The filling time required to maintain hawser forces of 44.48 kN (5 tons) or less was 19.6 min. This filling time resulted from a 20.0-min valve operation (Plate 10).

1.52-m (5-ft) lift

Experiments were conducted next to determine the performance of the filling system with an upper pool el 424 and a lower pool el 419. Plate 11 shows typical time-histories of water surface and hawser forces during filling with a 1.52-m (5-ft) lift and 5-min filling valve. The maximum downstream longitudinal hawser force was -100.53 kN (-11.3 tons) and occurred between 1 and 2 min into the filling operation. The maximum upstream transverse hawser forces measured during filling with a 1.52-m (5-ft) lift and 5-min valve were -15.12 kN (-1.7 tons) to the left side of the chamber and 6.23 kN (0.7 tons) to the right side of the chamber. The maximum downstream transverse hawser forces measured during filling with a 1.52-m (5-ft) lift and 5-min valve were -10.68 kN (-1.2 tons) to the left side of the chamber and 9.79 kN (1.1 tons) to the right side of the chamber. The transverse hawser forces did not exceed the 44.48-kN (5-ton) limit with the 1.52-m (5-ft) lift and 5-min filling valve.

To determine the filling time required to maintain 44.48-kN (5-ton) hawser forces or less with a 1.52-m (5-ft) lift, experiments were conducted with filling valve operations of 5, 10, and 15 min. The results from these experiments are shown in Plate 12. The filling time required to maintain hawser forces of 44.48 kN (5 tons) or less was 12.8 min. This filling time resulted from an 11.0-min valve operation (Plate 13).

Emptying Operations

Similar experiments were performed to determine the acceptable emptying times for 4.57-, 3.20- and 1.52-m (15-, 10.5-, and 5-ft) lifts. The performance of the emptying system was studied using five different design types. The design types were designated according to the number of vertical lift gates located in the 182.88-m (600-ft) extension that operated during the emptying. The design types were as follows:

Type 1: 10 vertical lift gates, 1 tainter valve (riverside).

Type 2: 6 vertical lift gates, 1 tainter valve (riverside).

Type 3: 4 vertical lift gates, 1 tainter valve (riverside).

Type 4: 2 vertical lift gates, 1 tainter valve (riverside).

Type 5: 0 vertical lift gates, 1 tainter valve (riverside).

Type 1 design: 4.57-m (15-ft) lift

Model experiments were performed to evaluate the performance of the type 1 design during emptying. Typical time-histories with a 4.57-m (15-ft) lift and a 5-min emptying valve are shown in Plate 14. The maximum downstream longitudinal hawser force measured was -80.96 kN (-9.1 tons) and occurred near 3 min into the emptying operation. The maximum upstream longitudinal hawser of 77.39 kN (8.7 tons) occurred when the lock water-surface elevation fell below the lower pool elevation. This is referred to as under emptying and is due to the inertial effects during emptying. Valve stroking can minimize these effects. The maximum transverse hawser force measured was -39.14 kN (-4.4 tons) and occurred on the downstream hawser in the left direction. This force occurred near 3 min into the emptying operation. The downstream transverse hawser forces are primarily towards the left side of the chamber during emptying. This occurs because all the emptying valves were located on this side of the chamber. To determine the emptying time required to maintain 44.48-kN (5-ton) hawser forces or less with a 4.57-m (15-ft) lift, experiments were conducted with emptying valve operations of 5, 10, 20, and 25 min. The results from these experiments are shown in Plate 15. An emptying time of 17.4 min was necessary to maintain hawser forces of 44.48 kN (5 tons) or less. A 17.4-min emptying time resulted with a 25.0-min emptying valve operation (Plate 16). In subsequent experiments, a different design type will be assigned to operations with less than 10 emptying valves.

Type 2 design: 4.57-m (15-ft) lift

Experiments were conducted to determine performance of the emptying system with six vertical lift gates in operation (type 2 design). The experiments were performed with the first two upstream valves and the last two downstream valves (I1, I2 and I9, I10 on Plate 2) taken out of operation. Similarly to filling, the downstream longitudinal hawser forces were higher than the upstream forces and the transverse forces were less than 44.48 kN (5 tons) for all valve operations tested.

To determine the emptying time required to maintain 44.48-kN (5-ton) hawser forces or less with a 4.57-m (15-ft) lift, experiments were conducted with emptying valve operations of 3, 5, and 10 min. The results from these experiments are shown in Plate 17. An emptying time of 11.8 min was necessary to maintain hawser forces of 44.48 kN (5 tons) or less. An 11.8-min emptying time resulted with a 6.0-min emptying valve operation (Plate 18).

Type 3 design: 4.57-m (15-ft) lift

Experiments were conducted to determine performance of the emptying system with four vertical lift gates in operation (type 3 design). The experiments were performed with the first, third, fifth, and seventh upstream valves and the last two downstream valves (I1, I3, I5, I7, I9, and I10 on Plate 2) taken out of operation. The downstream longitudinal hawser forces were higher than the upstream forces and the transverse forces were less than 44.48 kN (5 tons) for all valve operations tested. To determine the emptying time required to maintain 44.48-kN (5-ton) hawser forces or less with a 4.57-m (15-ft) lift, experiments were conducted with emptying valve operations of 1, 3, and 5 min. The results from these experiments are shown in Plate 19. An emptying time of 12.8 min was necessary to maintain hawser forces of 44.48 kN (5 tons) or less. A 12.8-min emptying time resulted with a 3.0-min emptying valve operation (Plate 20).

Type 4 design: 4.57-m (15-ft) lift

Experiments were conducted to determine performance of the emptying system with two vertical lift gates in operation (type 4 design). The experiments were performed with only the fourth and sixth upstream valve (I4 and I6 on Plate 2) in operation. Similar to the type 3 design, the downstream longitudinal hawser forces were higher than the upstream forces. The longitudinal and the transverse forces were less than 44.48 kN (5 tons) for all valve operations tested. Experiments were conducted with emptying valve operations of 1 and 5 min. The results from these experiments are shown in Plate 21. The lock emptied in 17.6 min with the fastest valve tested (Plate 22).

Type 5 design: 4.57-m (15-ft) lift

Experiments were conducted to determine performance of the emptying system with no vertical lift gates in operation (type 5 design). The downstream longitudinal hawser forces were lower than the upstream forces and the transverse forces were less than 44.48 kN (5 tons) for all valve operations tested.

To determine the emptying time required to maintain 44.48-kN (5-tons) hawser forces or less with a 4.57-m (15-ft) lift, experiments were conducted with emptying valve operations of 1, 3, and 5 min. The results from these experiments are shown in Plate 23. This design was very sensitive to the initial valve operation and thus the 3.0-min valve schedule significantly reduced the longitudinal hawser forces. During emptying operations with the tainter valve only, the valve controls the discharge initially at the beginning of the operation. The control then shifts to the outlet ports. With the 1.0- and 3.0-min empty valves, the control shifts to the ports early in operation and the emptying times are not much different. With the 5.0-min valve operation, the valve controls the flow longer and therefore the emptying time is longer than the 1.0- and 3.0- min valve. An emptying time of 32.2 min was necessary to maintain hawser forces of 44.48 kN (5 tons) or less. A 32.2-min emptying time resulted with a 3.0-min emptying valve operation (Plate 24).

Type 1 design: 3.2-m (10.5-ft) lift

Experiments were performed next to evaluate the performance of the type 1 design using a 3.2-m (10.5-ft) lift. Typical time-histories with a 3.2-m (10.5-ft) lift and a 5-min emptying valve are shown in Plate 25. The maximum downstream longitudinal hawser force measured was -91.63 kN (-10.3 tons) and occurred between 3 and 4 min into the emptying operation. The maximum transverse hawser force measured was -35.59 kN (-4.0 tons) and occurred on the downstream hawser in the left direction. This force occurred near 4 min into the emptying operation. To determine the emptying time required to maintain 44.48-kN (5-ton) hawser forces or less with a 3.2-m (10.5-ft) lift, experiments were conducted with emptying valve operations of 5, 10, and 15 min. The results from these experiments are shown in Plate 26. An emptying time of 14.3 min was necessary to maintain hawser forces 44.48 kN (5 tons) or less. A 14.3-min emptying time resulted with a 19.0-min emptying valve operation (Plate 27).

Type 2 design: 3.2-m (10.5-ft) lift

Experiments were conducted to determine performance of the emptying system with six vertical lift gates in operation (type 2 design). Similar to filling, the downstream longitudinal hawser forces were higher than the upstream forces and the transverse forces were less than 44.48 kN (5 tons) for all valve operations tested. To determine the emptying time required to maintain 44.48-kN (5-ton) hawser forces or less with a 3.2-m (10.5-ft) lift, experiments were conducted with emptying valve operations of 3, 5, and 10 min. The results from these experiments are shown in Plate 28. An emptying time of 10.4 min was necessary to maintain hawser forces of 44.48 kN (5 tons) or less. A 10.4-min emptying time resulted with a 7.0-min emptying valve operation (Plate 29).

Type 3 design: 3.2-m (10.5-ft) lift

Experiments were conducted to determine performance of the emptying system with four vertical lift gates in operation (type 3 design). The downstream longitudinal hawser forces were higher than the upstream forces and the transverse forces were less than 44.48 kN (5 tons) for all valve operations tested.

To determine the emptying time required to maintain 44.48-kN (5-ton) hawser forces or less with a 3.2-m (10.5-ft) lift, experiments were conducted with emptying valve operations of 1, 3, and 5 min. The results from these experiments are shown in Plate 30. An emptying time of 10.7 min was necessary to maintain hawser forces of 44.48 kN (5 tons) or less. A 10.7-min emptying time resulted with a 3.0-min emptying valve operation (Plate 31).

Type 4 design: 3.2-m (10.5-ft) lift

Experiments were conducted to determine performance of the emptying system with two vertical lift gates in operation (type 4 design). Similar to the type 3 design, the downstream longitudinal hawser forces were higher than the upstream forces, but the longitudinal and the transverse forces were less than 44.48 kN (5 tons) for all valve operations tested. Experiments were conducted with emptying valve operations of 1, and 5 min. The results from these experiments are shown in Plate 32. The lock emptied in 14.4 min with the fastest valve tested (Plate 33).

Type 5 design: 3.2-m (10.5-ft) lift

Experiments were conducted to determine performance of the emptying system with no vertical lift gates in operation (type 5 design). The downstream longitudinal hawser forces were lower than the upstream forces and the transverse forces were less than 44.48 kN (5 tons) for all valve operations tested. To determine the emptying time required to maintain 44.48-kN (5-ton) hawser forces or less with a 3.2-m (10.5-ft) lift, experiments were conducted with emptying valve operations of 1, 3, and 5 min. The results from these experiments are shown in Plate 34. This design was very sensitive to the initial valve operation and thus the 3.0-min valve schedule significantly reduced the longitudinal hawser forces. An emptying time of 25.7 min was necessary to maintain hawser forces of 44.48 kN (5 tons) or less. A 25.7-min emptying time resulted with a 3.0-min emptying valve operation (Plate 35).

Type 1 design: 1.52-m (5-ft) lift

Experiments were performed next to evaluate the performance of the type 1 design using a 1.52-m (5-ft) lift. Typical time-histories with a 1.52-m (5-ft) lift and a 5-min emptying valve are shown in Plate 36. The maximum downstream longitudinal hawser force measured was 75.62 kN (8.5 tons) and occurred between 3 and 4 min into the emptying operation. The maximum transverse hawser force measured was -27.58 kN (-3.1 tons) and occurred on the down-stream hawser in the left direction. This force occurred near 4 min into the emptying operation. To determine the emptying time required to maintain 44.48-kN (5-ton) hawser forces or less with a 1.52-m (5-ft) lift, experiments were conducted with emptying valve operations of 5, 10, and 15 min. The results from these experiments are shown in Plate 37. An emptying time of 9.8 min was necessary to maintain hawser forces 44.48 kN (5 tons) or less. A 9.8-min emptying time resulted with a 14.5-min emptying valve operation (Plate 38).

Type 2 design: 1.52-m (5-ft) lift

Experiments were conducted to determine performance of the emptying system with six vertical lift gates in operation (type 2 design). In this case, the downstream longitudinal hawser forces were higher than the upstream forces only for the first two valves tested. The transverse forces were less than 44.48 kN (5 tons) for all valve operations tested. To determine the emptying time required to maintain 44.48-kN (5-ton) hawser forces or less with a 1.52-m (5-ft) lift, experiments were conducted with emptying valve operations of 3, 5, and 10 min. The results from these experiments are shown in Plate 39. An emptying time of 7.2 min was necessary to maintain hawser forces of 44.48 kN (5 tons) or less. A 7.2-min emptying time resulted with a 5.5-min emptying valve operation (Plate 40).

Type 3 design: 1.52-m (5-ft) lift

Experiments were conducted to determine performance of the emptying system with four vertical lift gates in operation (type 3 design). The downstream longitudinal hawser forces were higher than the upstream forces and the transverse forces were less than 44.48 kN (5 tons) for all valve operations tested. To determine the emptying time required to maintain 44.48-kN (5-ton) hawser forces or less with a 1.52-m (5-ft) lift, experiments were conducted with emptying valve operations of 1, 3, and 5 min. The results from these experiments are shown in Plate 41. An emptying time of 7.4 min was necessary to maintain hawser forces of 44.48 kN (5 tons) or less. A 7.4-min emptying time resulted with a 3.0-min emptying valve operation (Plate 42).

Type 4 design: 1.52-m (5-ft) lift

Experiments were conducted to determine performance of the emptying system with two vertical lift gates in operation (type 4 design). Similarly to the other lifts tested, the longitudinal and the transverse forces were less than 44.48 kN (5 tons) for all valve operations tested. Experiments were conducted with emptying valve operations of 1 and 5 min. The results from these experiments are shown in Plate 43. For the fastest valve tested, the lock emptied in 9.3 min (Plate 44).

Type 5 design: 1.52-m (5-ft) lift

Experiments were conducted to determine performance of the emptying system with no vertical lift gates in operation (type 5 design). The upstream longitudinal hawser forces were higher than the downstream forces and the transverse forces were less than 44.48 kN (5 tons) for all valve operations tested. To determine the emptying time required to maintain 44.48-kN (5-ton) hawser forces or less with a 1.52-m (5-ft) lift, experiments were conducted with emptying valve operations of 1, 3, and 5 min. Results from these experiments are shown in Plate 45. As well as in other lifts tested, type 4 design was very sensitive to the initial valve operation and thus the 3.0-min valve significantly reduced the longitudinal hawser forces. An emptying time of 17.4 min was

necessary to maintain hawser forces of 44.48 kN (5 tons) or less. A 17.4 min emptying time resulted with a 2.5-min emptying valve operation (Plate 46).

4 Summary and Recommendations

Valve operations required to achieve acceptable chamber performance with the types 1-5 design filling and emptying systems are summarized in Tables 1 and 2. Each design type included the existing tainter valve during emptying. Results with the type 1 design (10 vertical slide valves and the existing tainter valve) indicated that a 17.4-min emptying time was required to maintain hawser forces of 44.48 kN, 5 tons, or less with a 4.57-m (15-ft) lift. This required an extremely slow emptying valve of 25 min. The emptying valve had to be operated very slowly to avoid high hawser forces in the initial portion of the emptying operation. The valve time for these conditions was longer than the empty time, which indicated that a variable speed valve operation should be used. The time restriction for this study did not allow testing of variable speed valves. Due to the high hawser forces measured during emptying with the type 1 design and reasonable valves speeds, the chamber performance was actually improved with fewer vertical slide valves in operation.

Chamber performance with the type 2 design (six vertical slide gates and the existing tainter valve) showed a significant improvement over the type 1 design. The emptying time was reduced to 11.2 min with the 4.57-m (15-ft) lift, and the valve speed was 6 min. This empty time was considered acceptable for this type of lock modification. Chamber performance with the type 3 design (four vertical slide valves and the existing tainter valve) was also considered acceptable. The lock emptied in 12.8 min with the 4.57-m (15-ft) lift and the valve speed was 4 min. Plate 47 shows the acceptable emptying times required to maintain hawser forces of 44.48 kN (5 tons) or less with the 4.57-m (15-ft) lift. The types 2 and 3 designs provided the best chamber performance. Plates 48 and 49 with the lower lifts support this observation. With the lower lifts, the difference in empty times between the types 2 and 3 designs becomes less and since these lower lifts are more common, the type 3 design is recommended. This design should be more economical and will present fewer structural design difficulties.

The filling system for this study was not modified. Using the existing side port system for the 600-ft lock to fill the 1,200-ft extended lock will be inherently slow since the filling is from one end of the chamber. The system is unbalanced and unable to provide an even flow distribution within the chamber. Table 2 lists the filling times required to maintain acceptable chamber performance with lifts

Table 1
Emptying Operation

Design	Number of Supplemental Emptying Valves	Lift					
		4.57 m (15 ft)		3.20 m (10.5 ft)		1.52 m (5 ft)	
		Valve Time (min)	Emptying Time[1] (min)	Valve Time (min)	Emptying Time[1] (min)	Valve Time (min)	Emptying Time[1] (min)
Type 1	10	25	17.4	19	14.3	14.5	9.8
Type 2	6	6	11.2	7.5	10.4	5.5	7.2
Type 3	4	3	12.8	3	10.7	3	7.4
Type 4	2	1	17.6	1	14.4	1	9.3
Type 5	0	3	32.3	3	25.7	2.5	17.4

[1]Emptying time to maintain hawser forces under 44.48 kN (5 tons)

Table 2
Filling Operation with Original Design

Lift (m)	Valve Time (min)	Filling Time (min)
4.57	23	23.1
3.20	20	20.2
1.52	11	12.8

of 4.57, 3.04, and 1.52 m (15, 10, and 5 ft). A filling time of 23.1 min was required with the 4.57-m (15-ft) lift. Slow filling valves are required to maintain minimal water-surface differences between the upper and lower portions of the chamber. A 23-min valve was required with the 4.57-m (15-ft) lift. These slow times were expected.

This study revealed that having more additional emptying valves did not improve the chamber performance of the lock extension. With more valves, slower valve times were required to prevent high hawser forces. The type 3 design with valve No. I2, I4, I6, and I8 (see Plate 2) in operation performed the best for the range of conditions tested. Spreading the valve locations over the lower half of the chamber as with the type 3 design is preferable over locating them too close to one another. When outlets discharge directly into the area below the stilling basin, a differential may exist between the lock chamber and river especially during spillway discharges. Precautions may need to be taken if this condition is expected.

Research on lock extension projects has shown that the fastest system would probably be one that provides the same filling and emptying times as the existing smaller lock. To achieve this type of operation, an additional filling and emptying system would be required for the extended portion of the lock chamber. A completely separate system with another intake, filling and emptying system and outlet could be developed to match the performance of the existing system. The additional F and E system could be a side port type, a lateral, or a floor longitudinal culvert type. An economic investigation would be needed to select the desired system.

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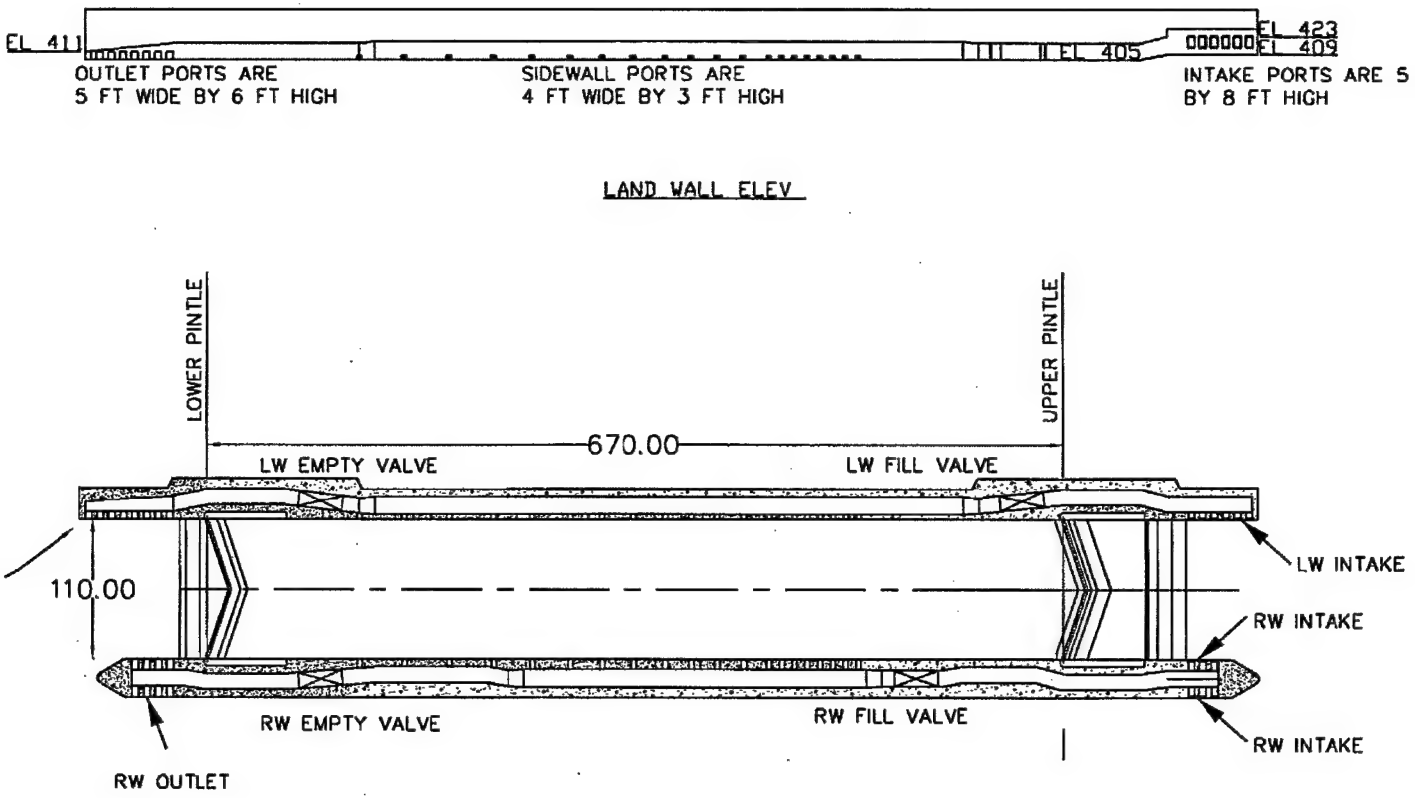
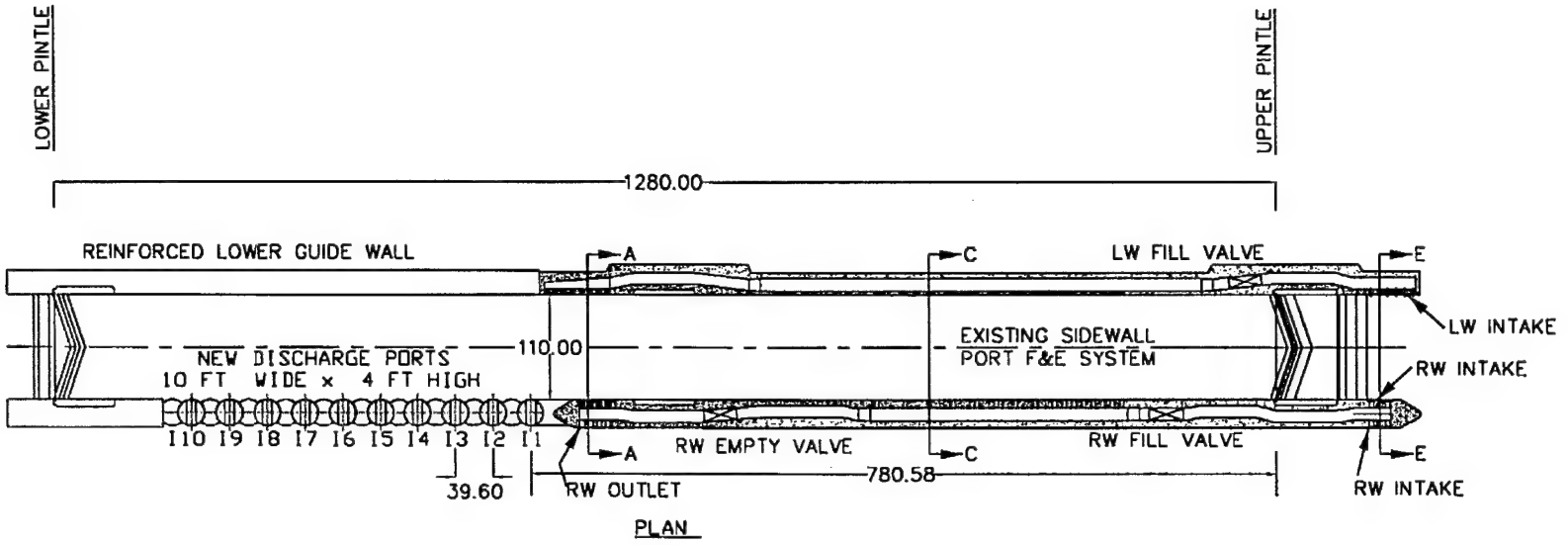


DIMENSIONS ARE IN FT
(To convert feet to meters, multiply by 0.3048)

EXISTING LOCK NO. 25
PLAN AND ELEV

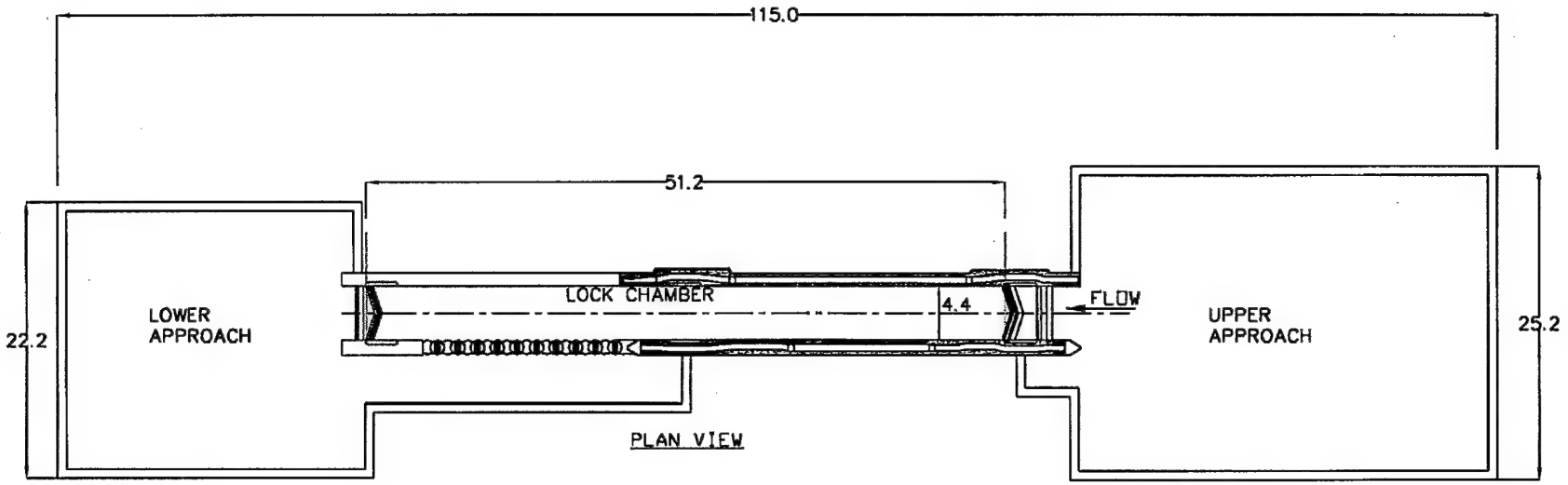
Plate 1

Plate 2



DIMENSIONS ARE IN FT

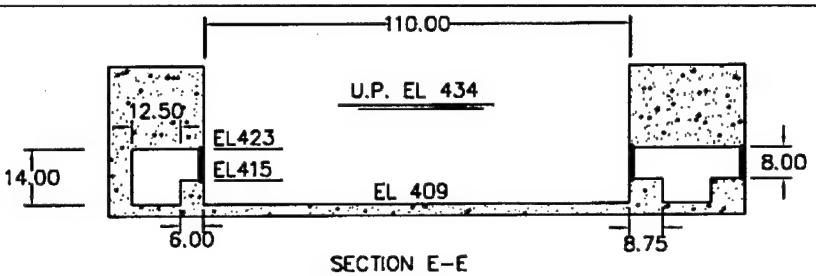
LOCK EXTENSION
DETAILS



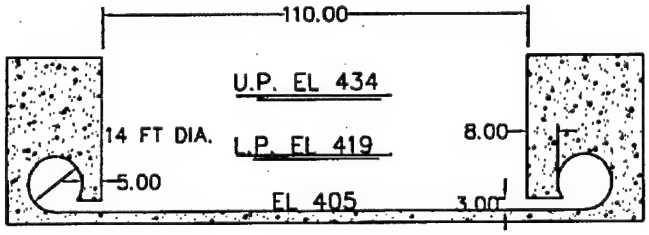
DIMENSIONS ARE IN FT

UPPER MS F & E MODEL
PLAN LAYOUT

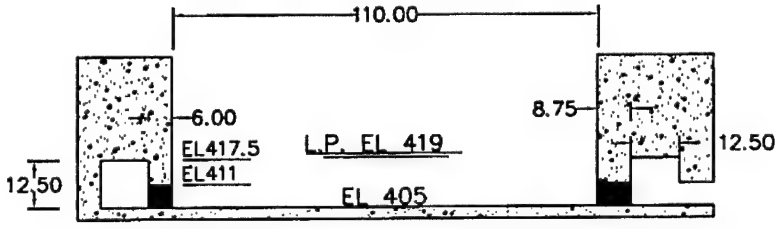
Plate 3



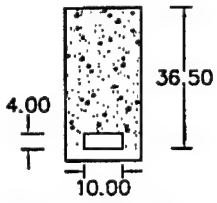
SECTION E-E
AT INTAKE



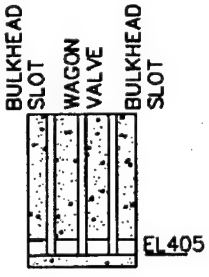
SECTION C-C
AT CIRCULAR CULVERT



SECTION A-A
AT OUTLET



FRONT VIEW OF
DISCHARGE PORTS

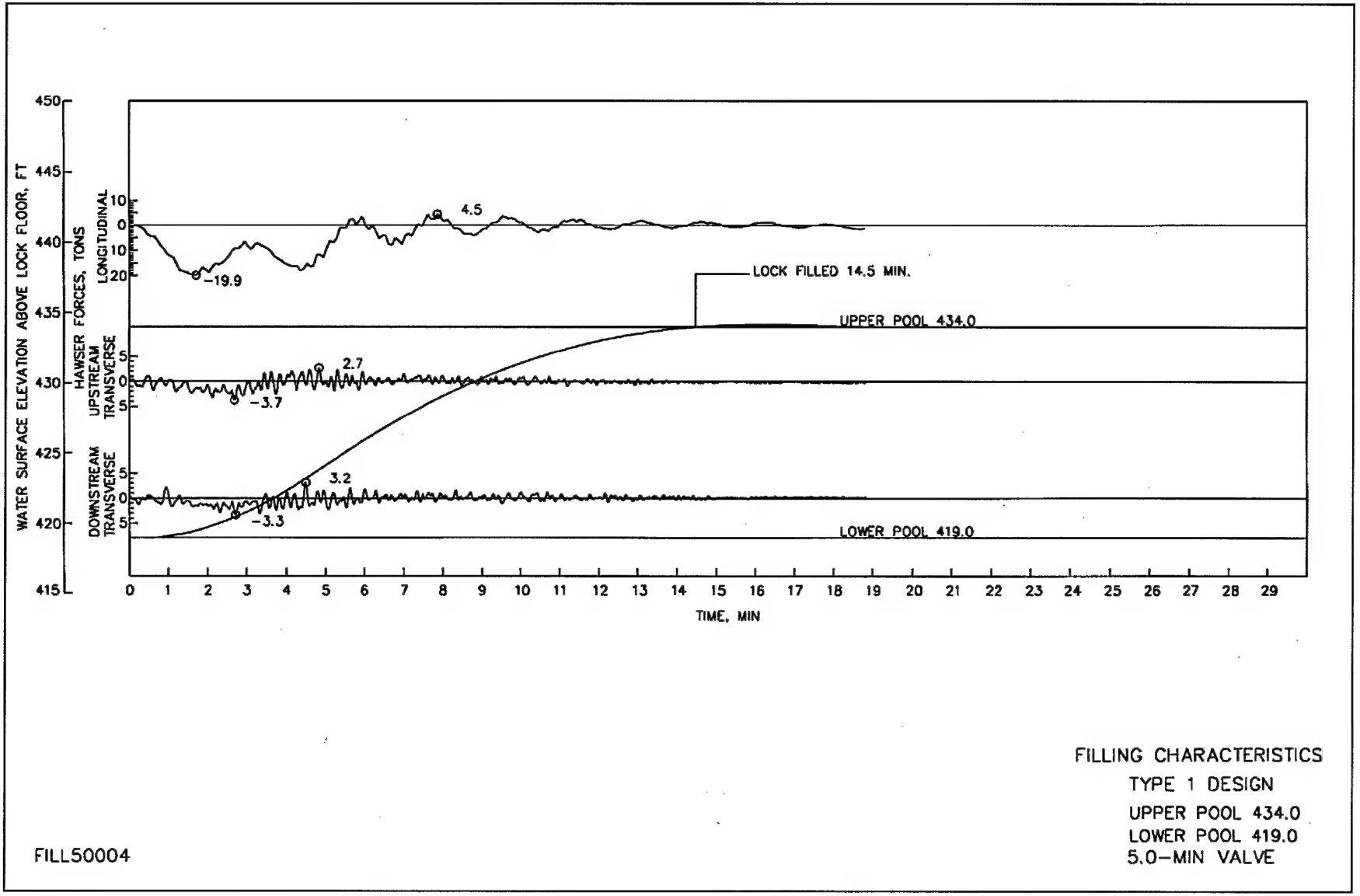


SECTION VIEW OF DISCHARGE PORTS

DIMENSIONS ARE IN FT
LOCK 25 ELEVATIONS

LOCK EXTENSION
SECTIONS

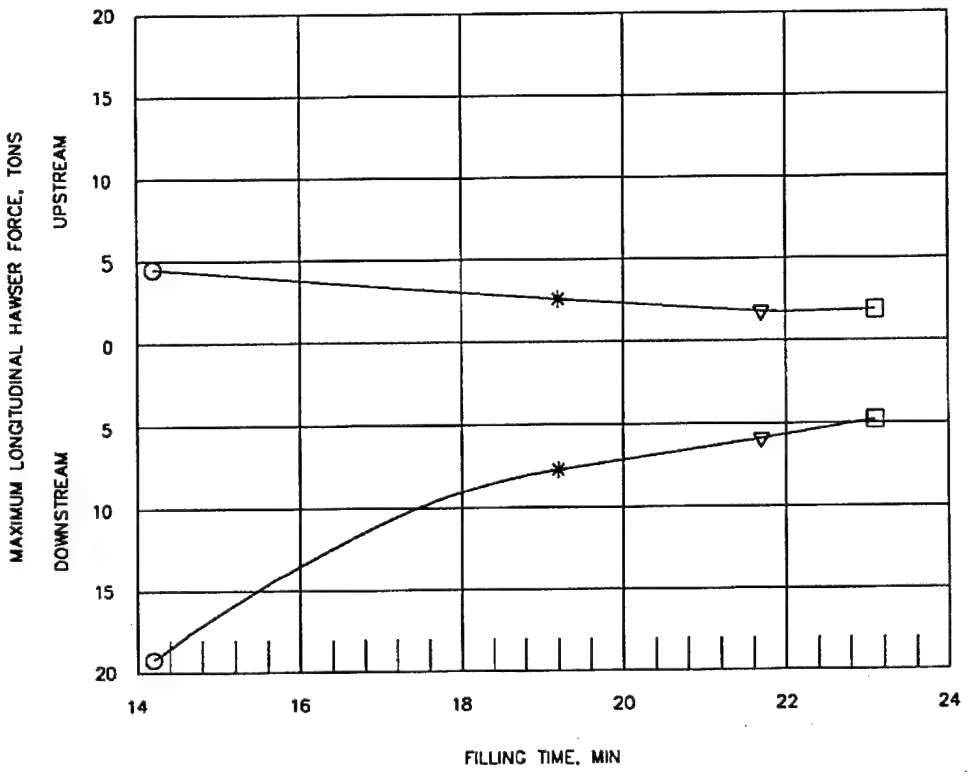
Plate 4

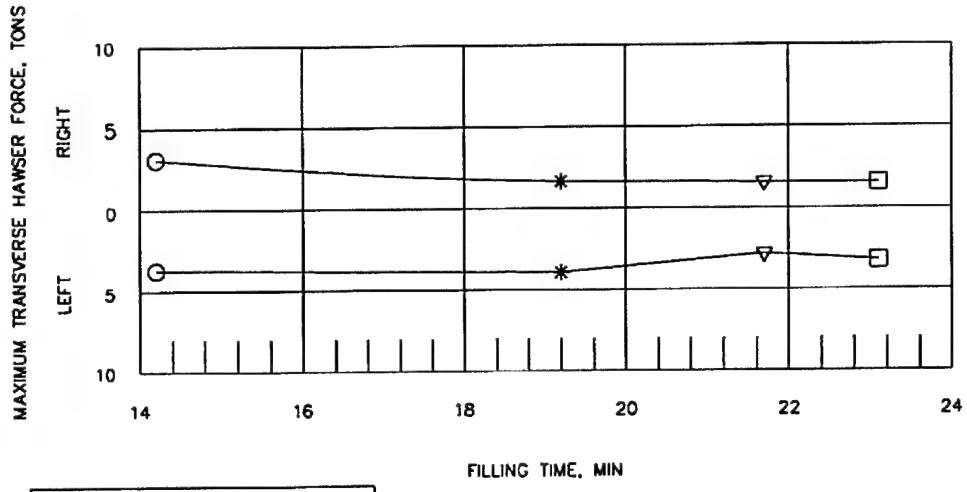


FILLING CHARACTERISTICS
TYPE 1 DESIGN
UPPER POOL 434.0
LOWER POOL 419.0
5.0-MIN VALVE

FILL50004

Plate 5

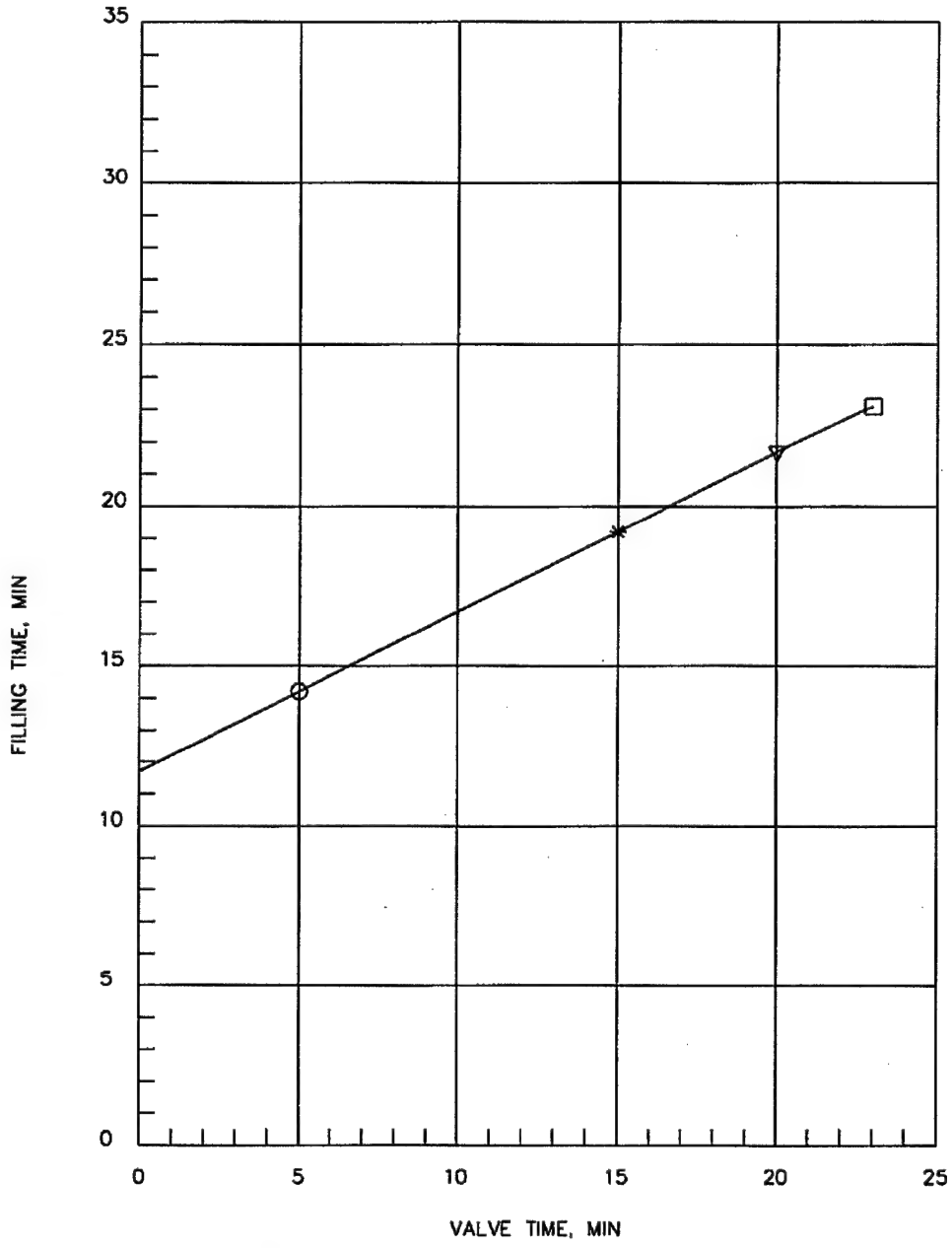




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	5
✳	15
▽	20
□	23

HAWSER FORCES
DURING FILLING
TYPE 1 DESIGN
15-ft Lift

Plate 6

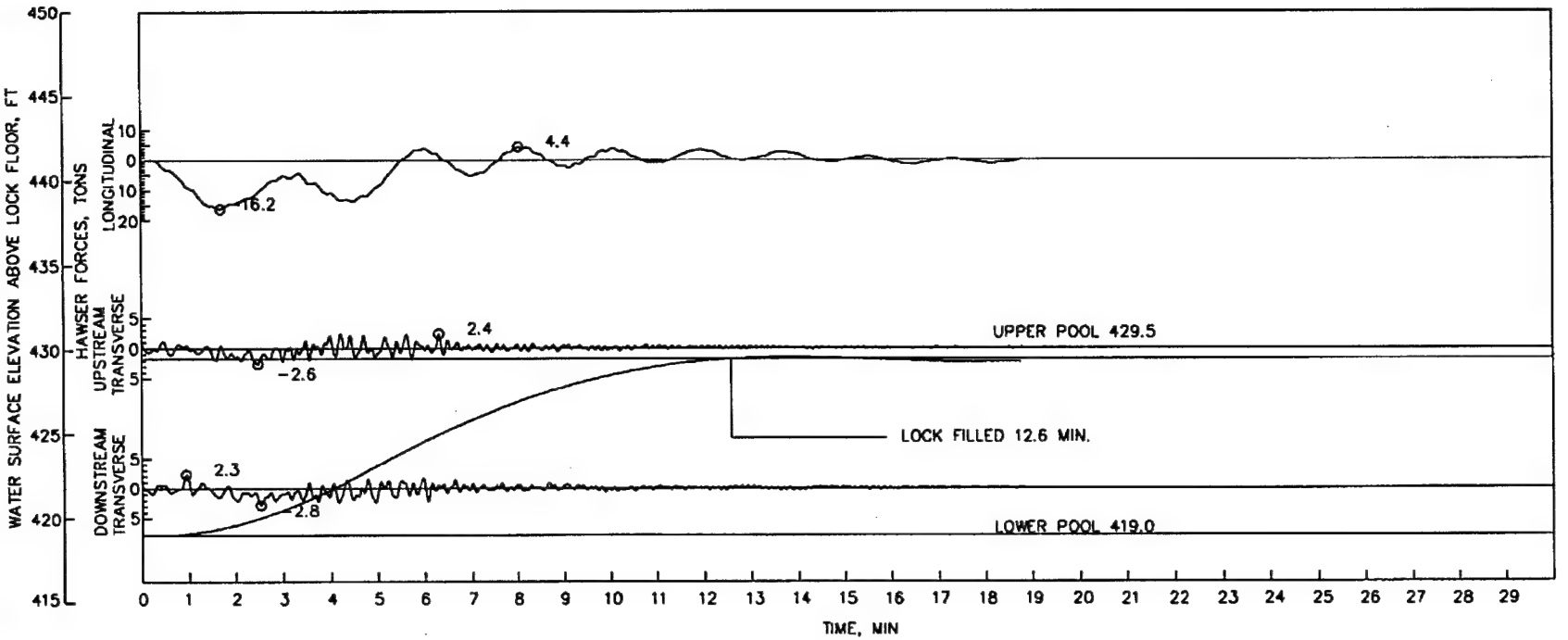


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	5
✳	15
▽	20
□	23

OPERATION TIMES
DURING FILLING
TYPE 1 DESIGN
15-ft Lift

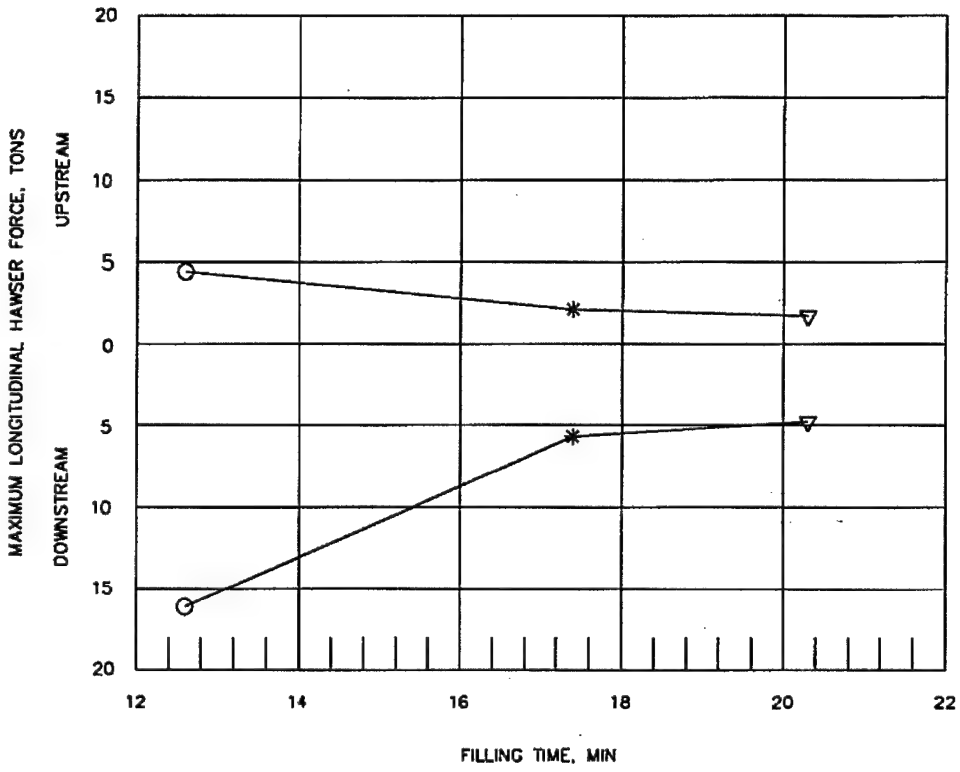
Plate 7

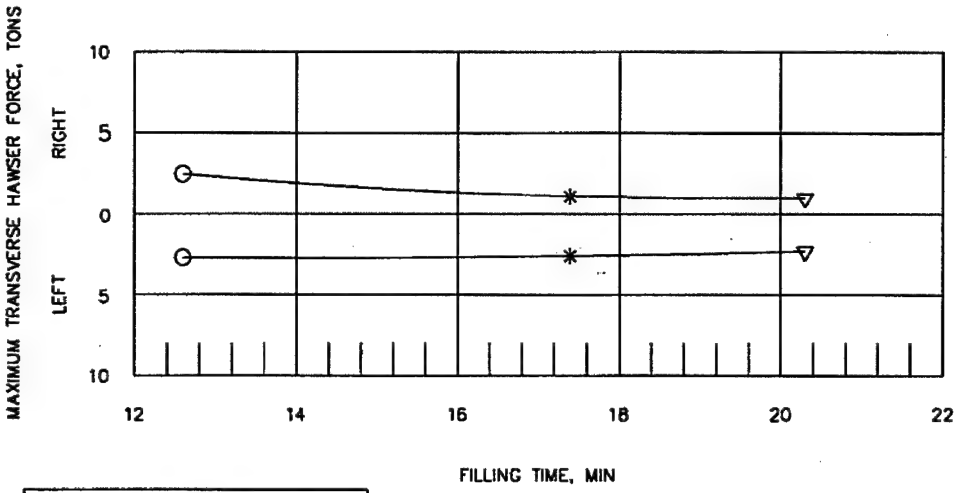
Plate 8



FILLING CHARACTERISTICS
TYPE I DESIGN
UPPER POOL 429.5
LOWER POOL 419.0
5.0−MIN VALVE

FILL5012

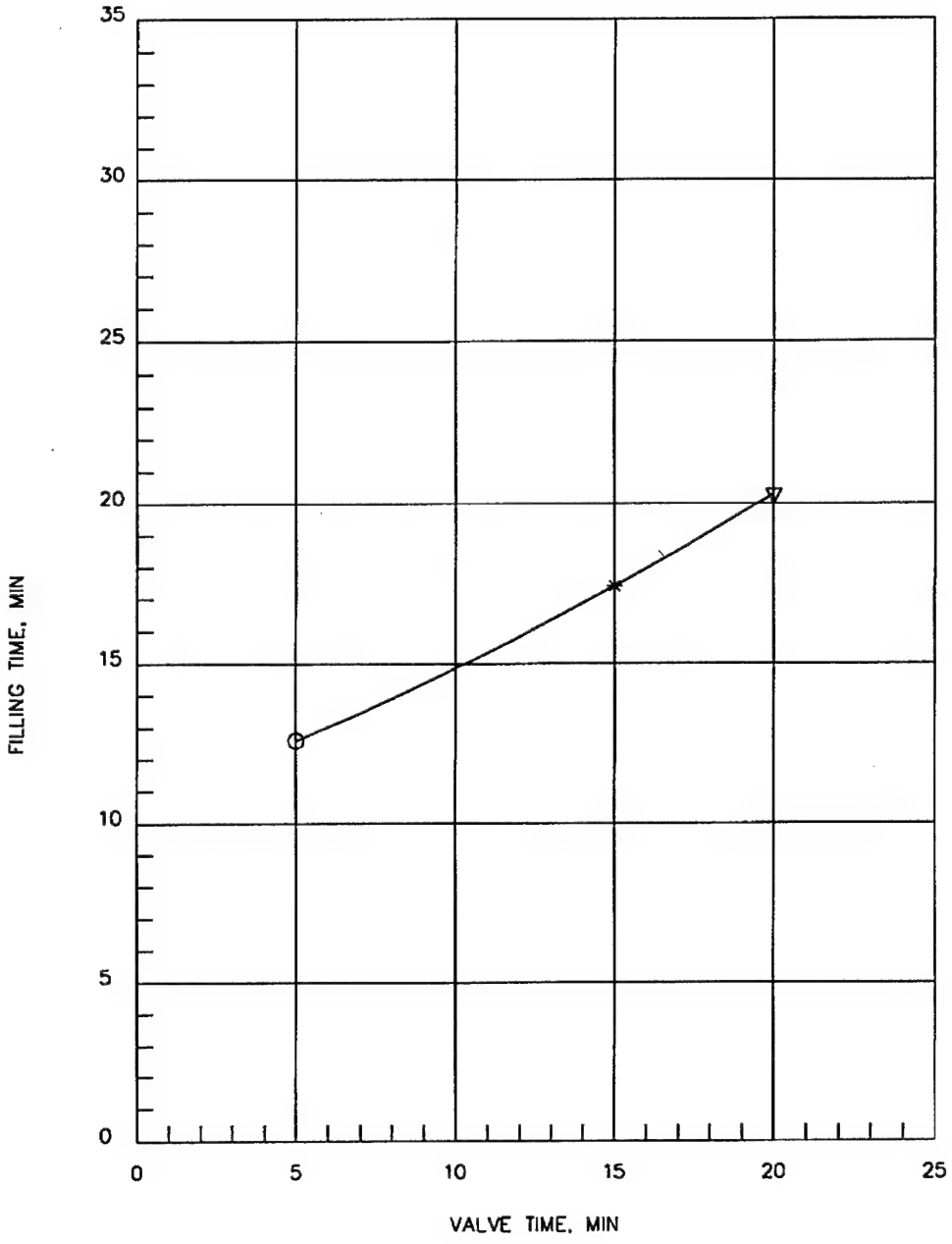




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	5
✳	15
▽	20

HAWSER FORCES
DURING FILLING
TYPE 1 DESIGN
10.5–ft Lift

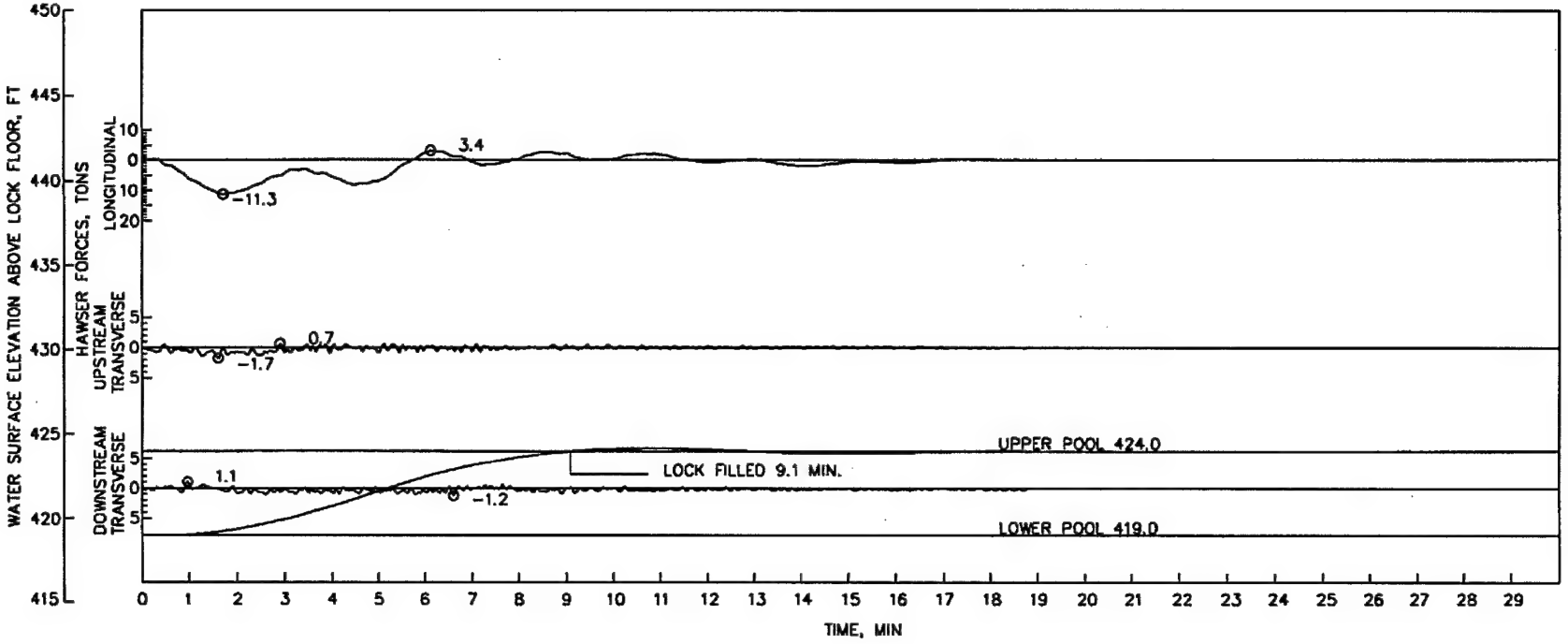
Plate 9



LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	5
✳	15
▽	20

OPERATION TIMES
DURING FILLING
TYPE 1 DESIGN
10.5–ft Lift

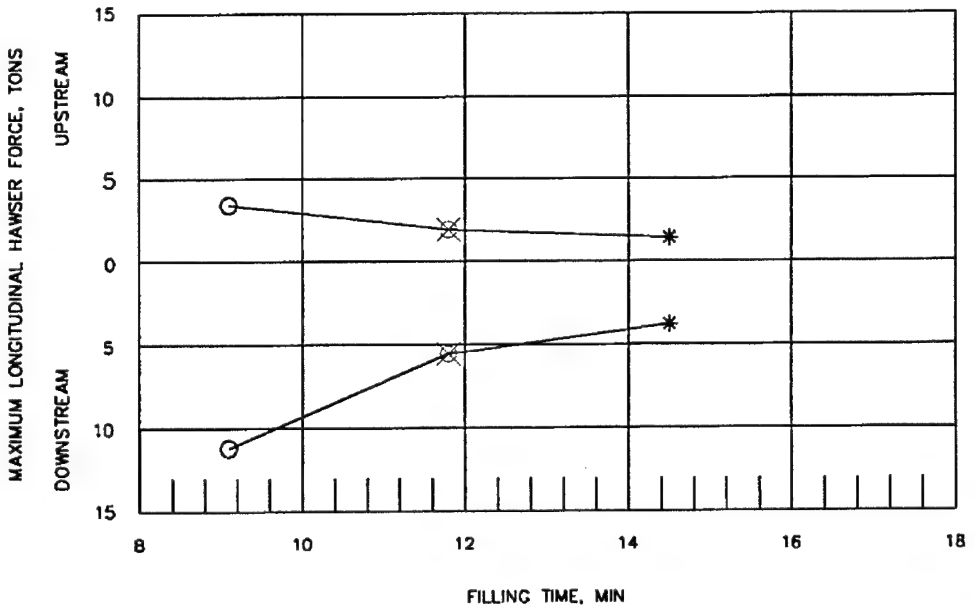
Plate 10

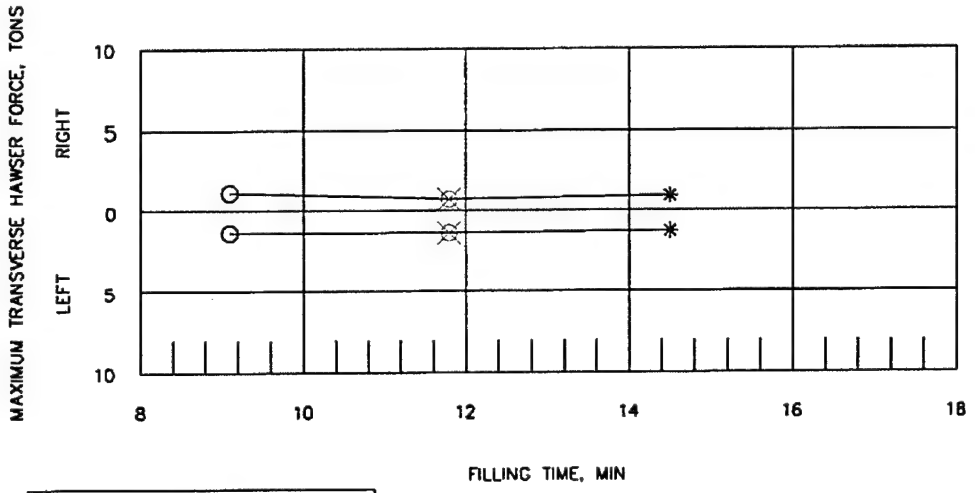


FILLING CHARACTERISTICS
TYPE 1 DESIGN
UPPER POOL 424.0
LOWER POOL 419.0
5.0-MIN VALVE

FILL5050

Plate 11

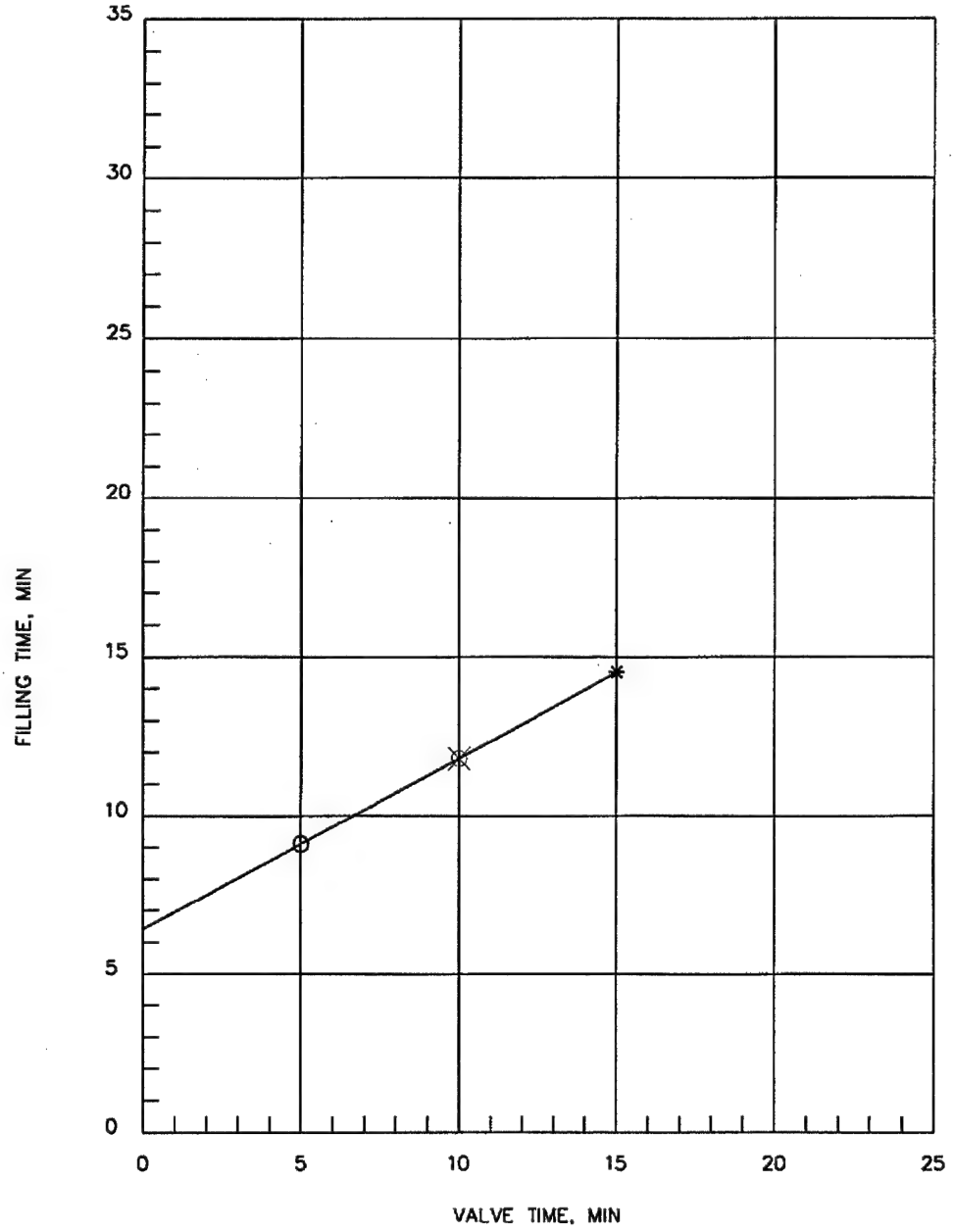




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
O	5
⊠	10
*	15

HAWSER FORCES
DURING FILLING
TYPE 1 DESIGN
5-ft Lift

Plate 12

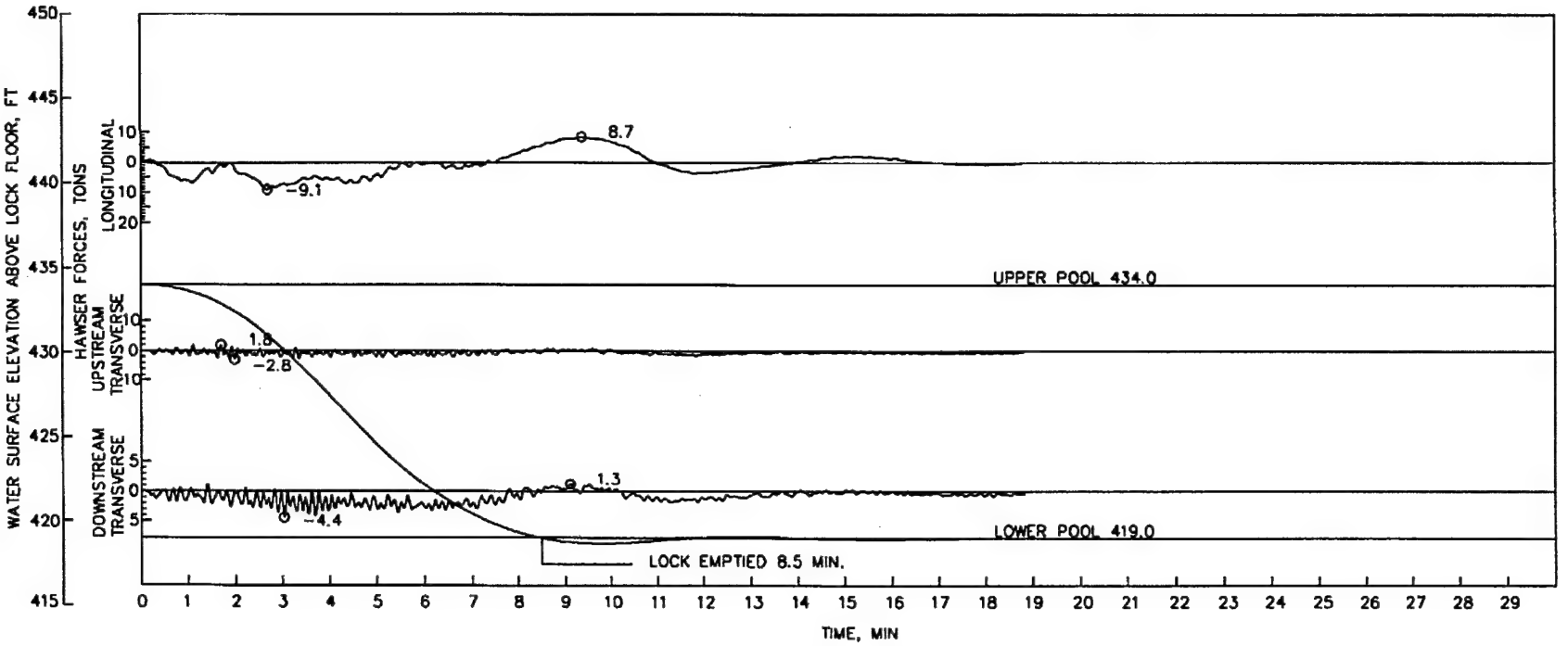


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	5
⊗	10
*	15

OPERATION TIMES
DURING FILLING
TYPE 1 DESIGN
5-ft Lift

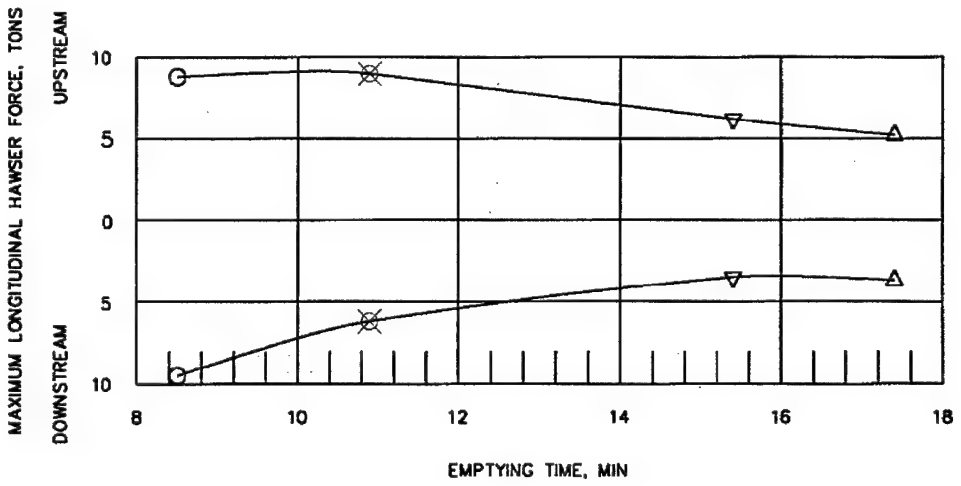
Plate 13

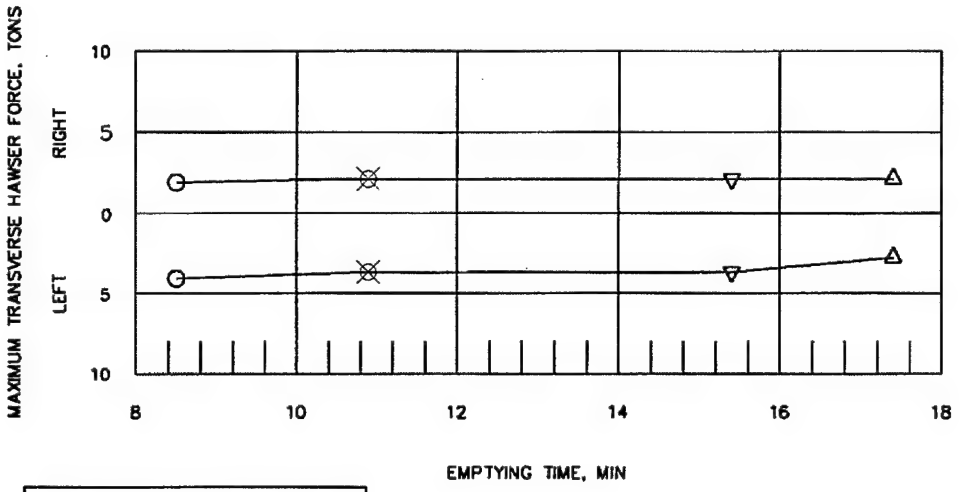
Plate 14



EMPTYING CHARACTERISTICS
TYPE 1 DESIGN
UPPER POOL 434.0
LOWER POOL 419.0
5.0-MIN VALVE

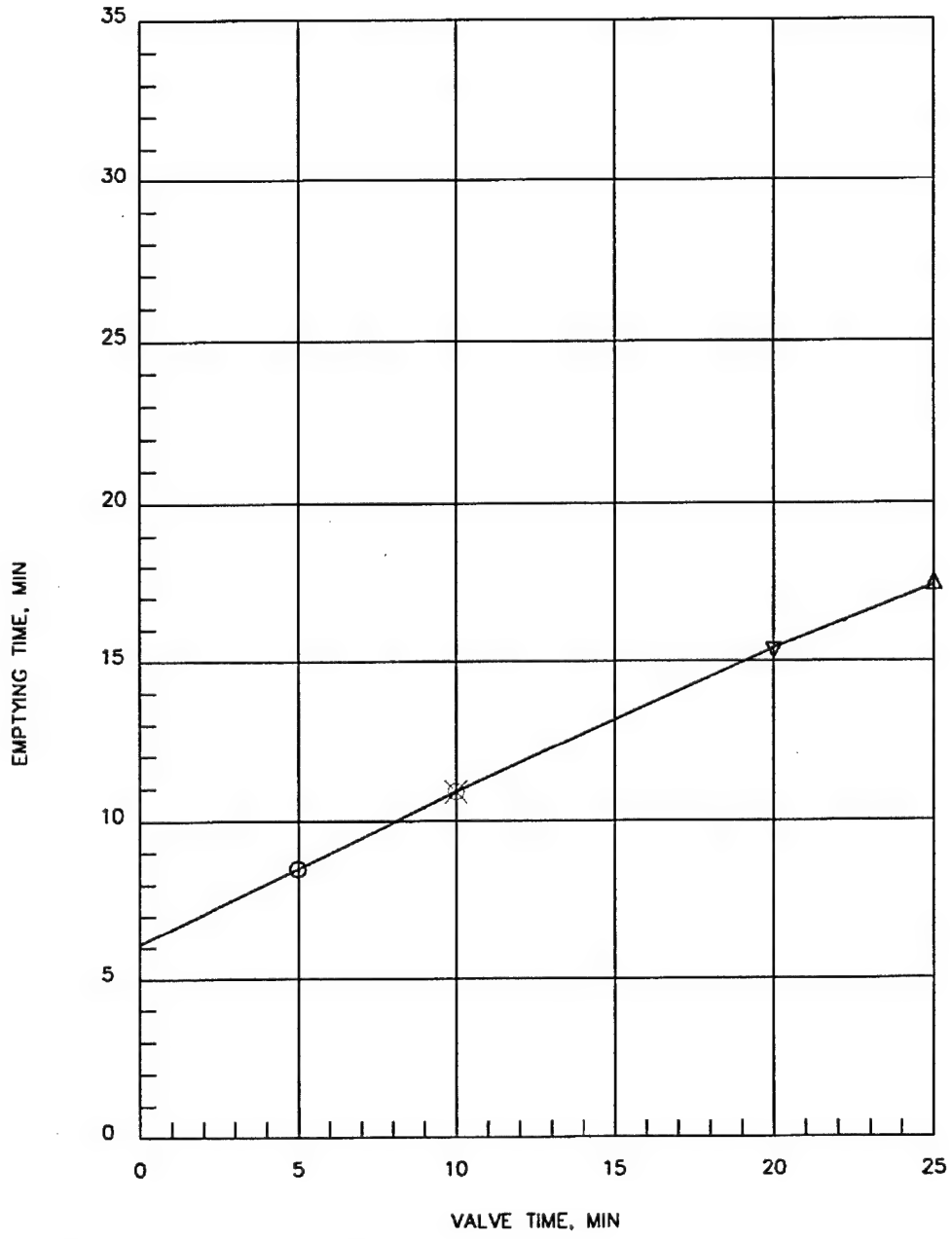
EMP5011





LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	5
⊠	10
▽	20
△	25

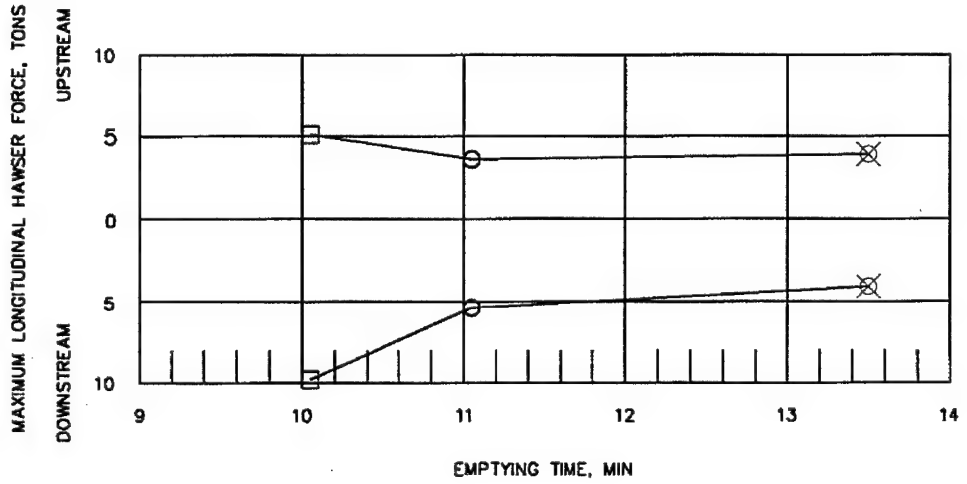
HAWSER FORCES
DURING EMPTYING
TYPE 1 DESIGN
15-ft Lift

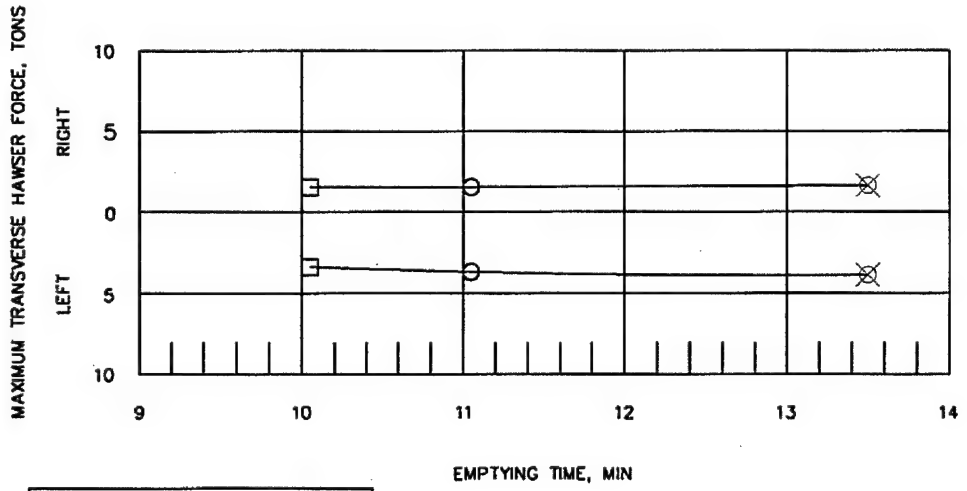


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	5
⊗	10
▽	20
△	25

OPERATION TIMES
DURING EMPTYING
TYPE 1 DESIGN
15-ft Lift

Plate 16

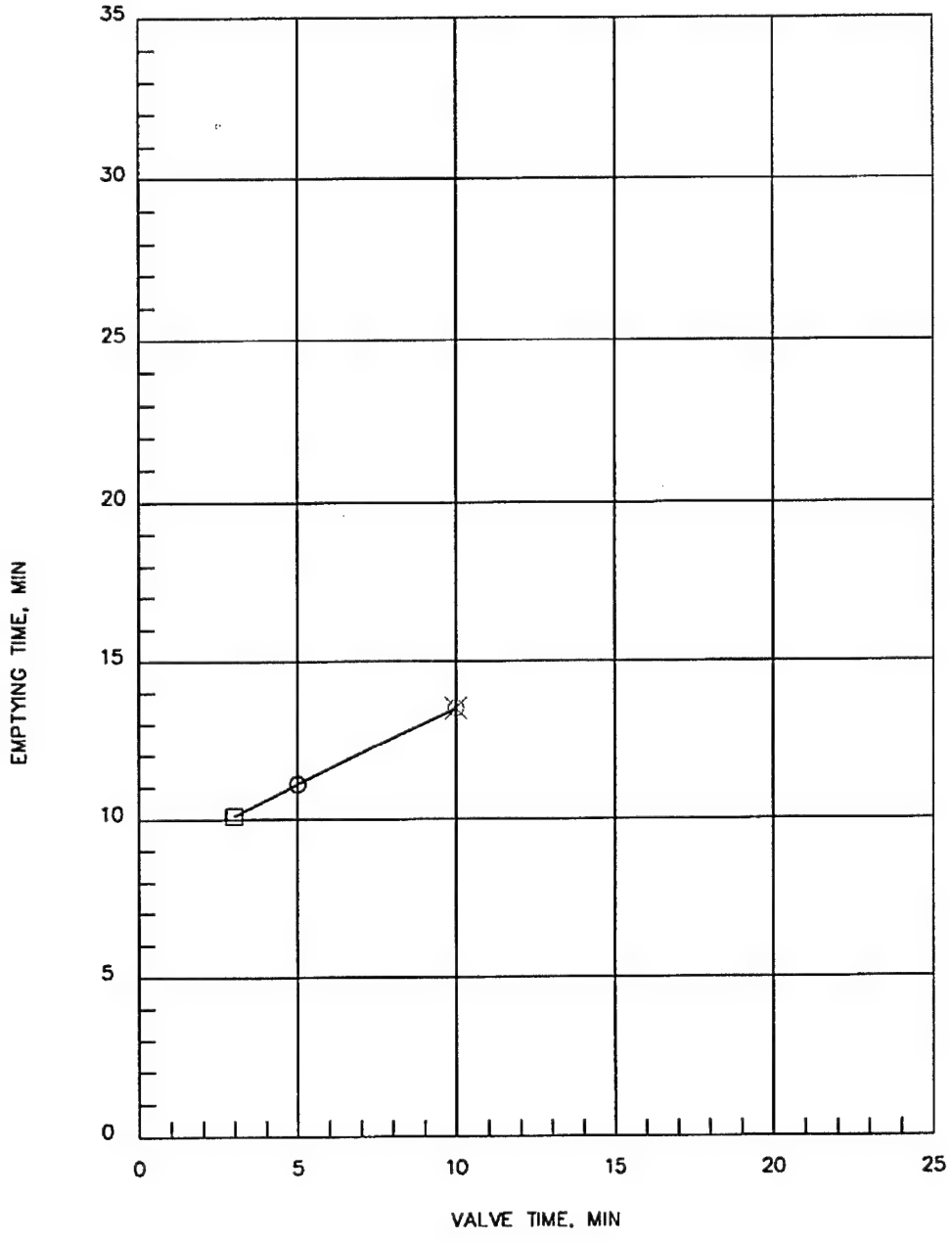




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
□	3
○	5
⊗	10

HAWSER FORCES
DURING EMPTYING
TYPE 2 DESIGN
15-ft Lift

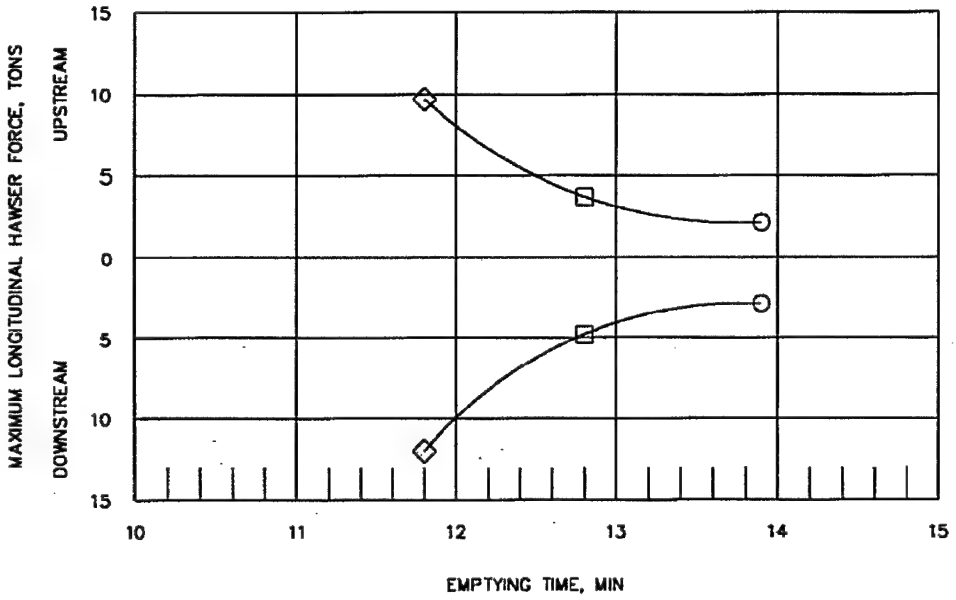
Plate 17

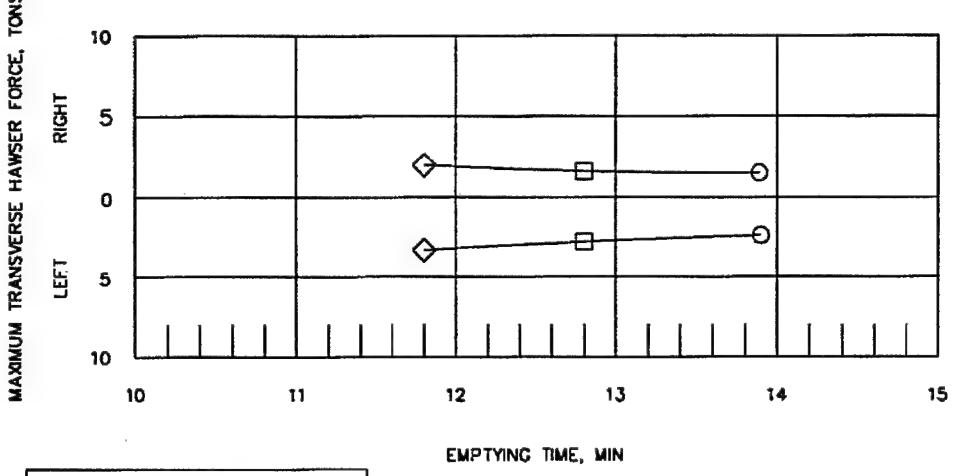


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
□	3
○	5
⊘	10

OPERATION TIMES
DURING EMPTYING
TYPE 2 DESIGN
15–ft Lift

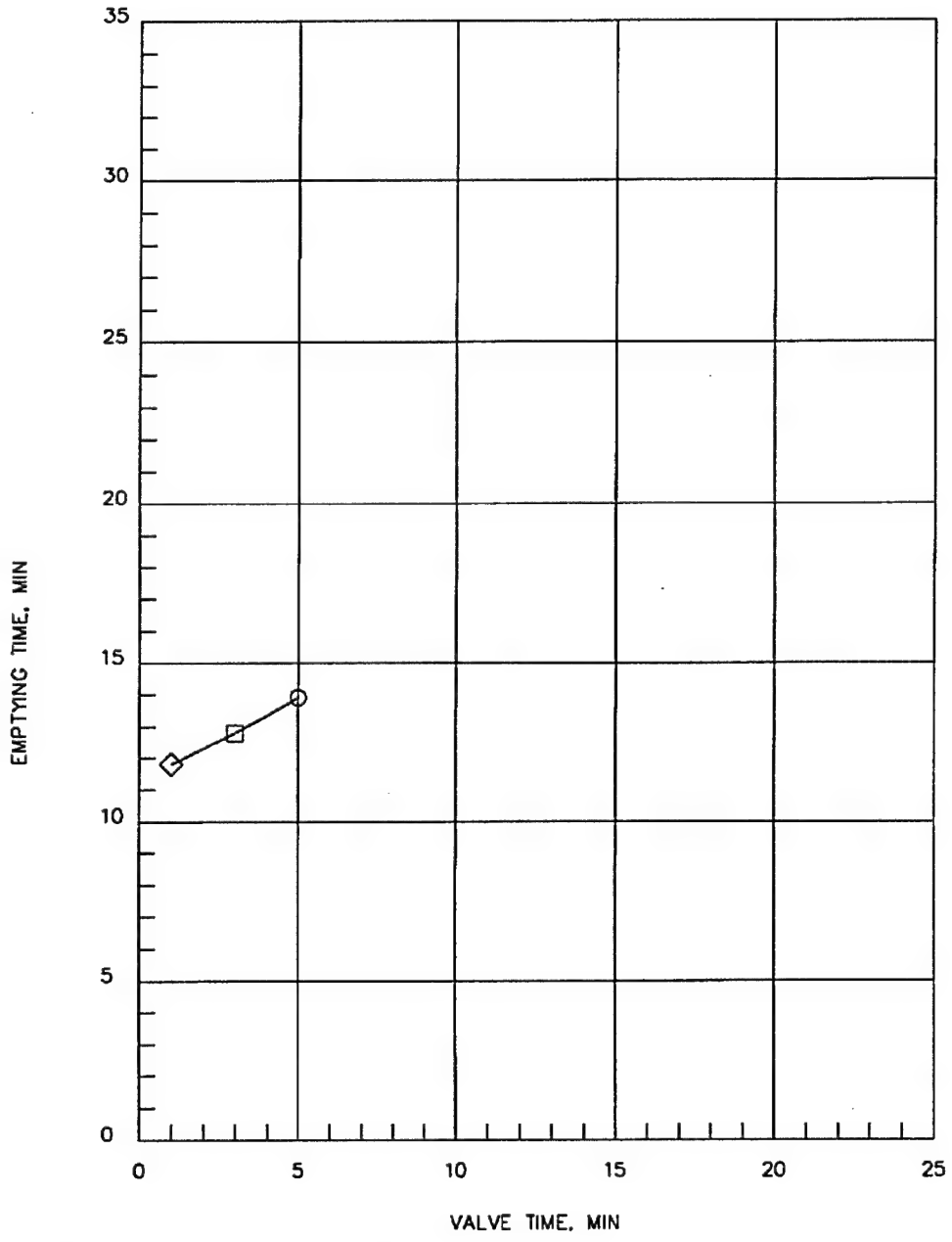
Plate 18





LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
□	3
○	5

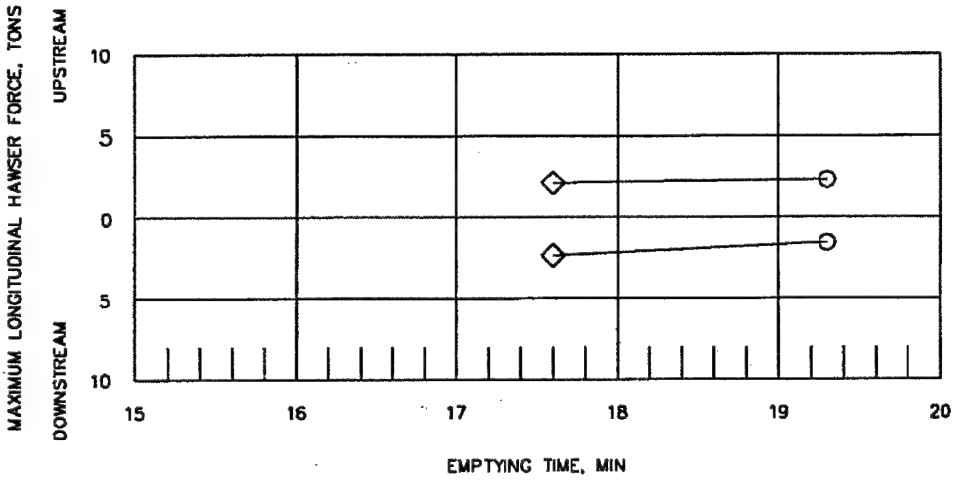
HAWSER FORCES
DURING EMPTYING
TYPE 3 DESIGN
15–ft Lift

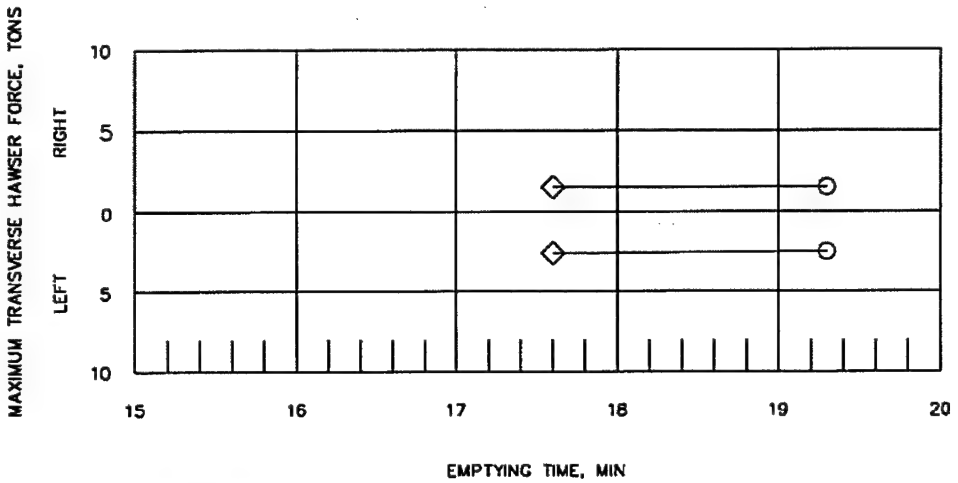


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
□	3
○	5

OPERATION TIMES
DURING EMPTYING
TYPE 3 DESIGN
15–ft Lift

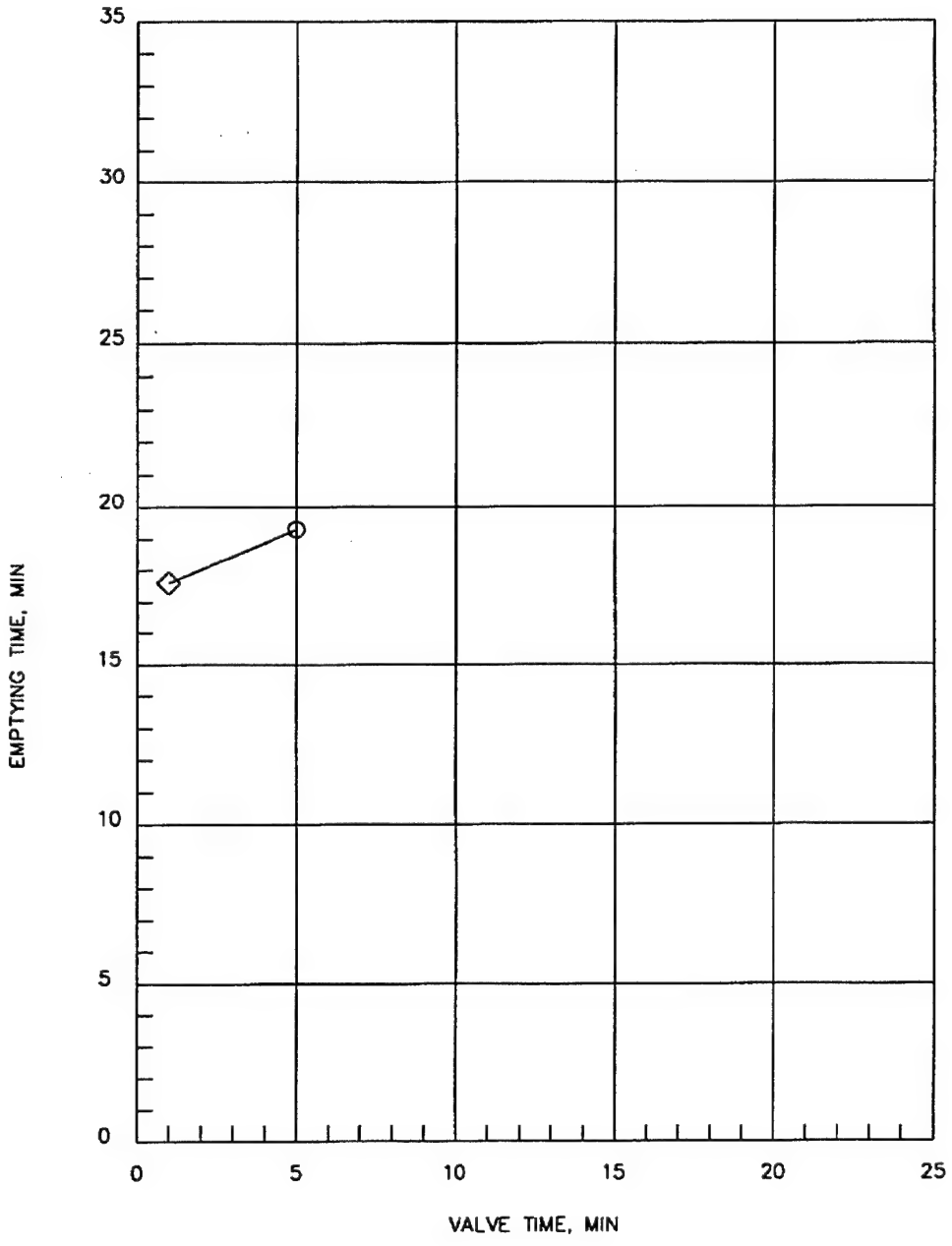
Plate 20





LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
○	5

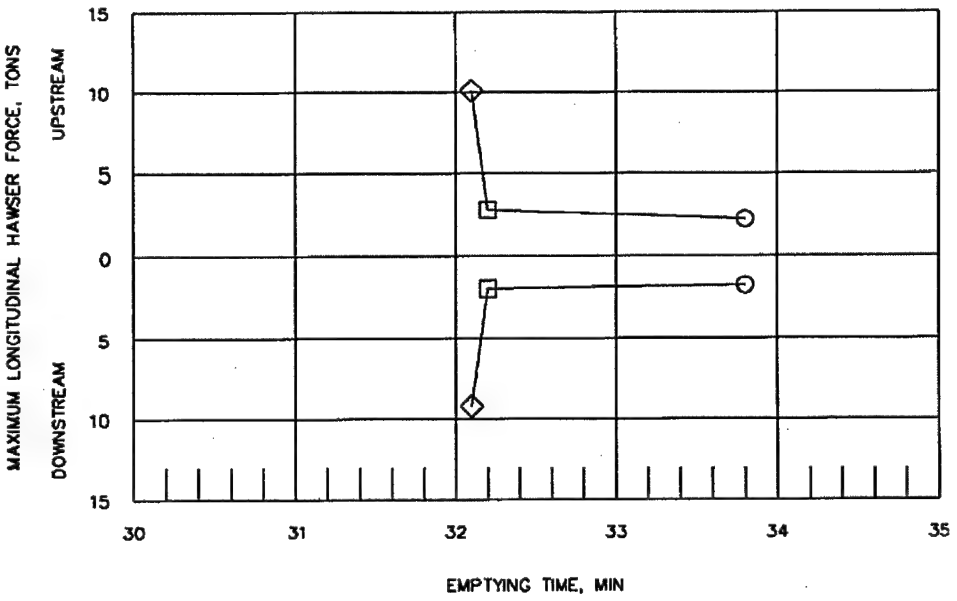
HAWSER FORCES
DURING EMPTYING
TYPE 4 DESIGN
15-ft Lift

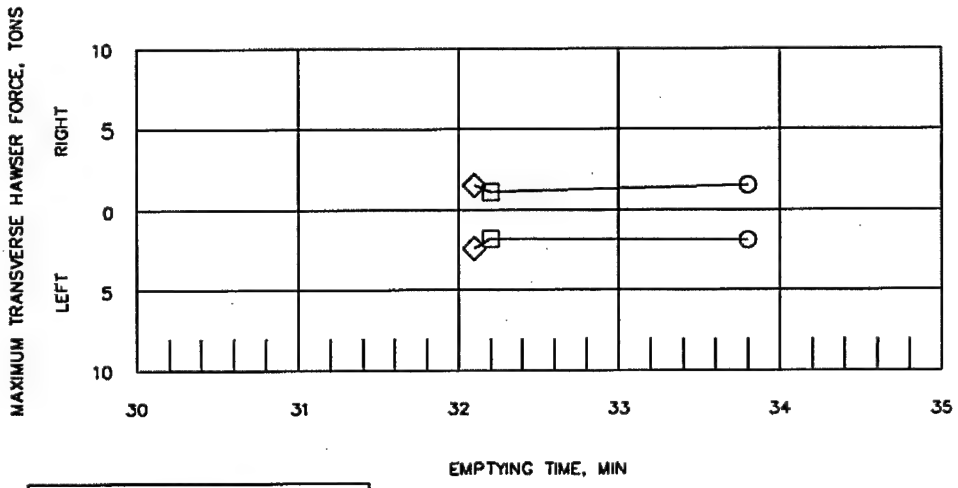


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
○	5

OPERATION TIMES
DURING EMPTYING
TYPE 4 DESIGN
15–ft Lift

Plate 22

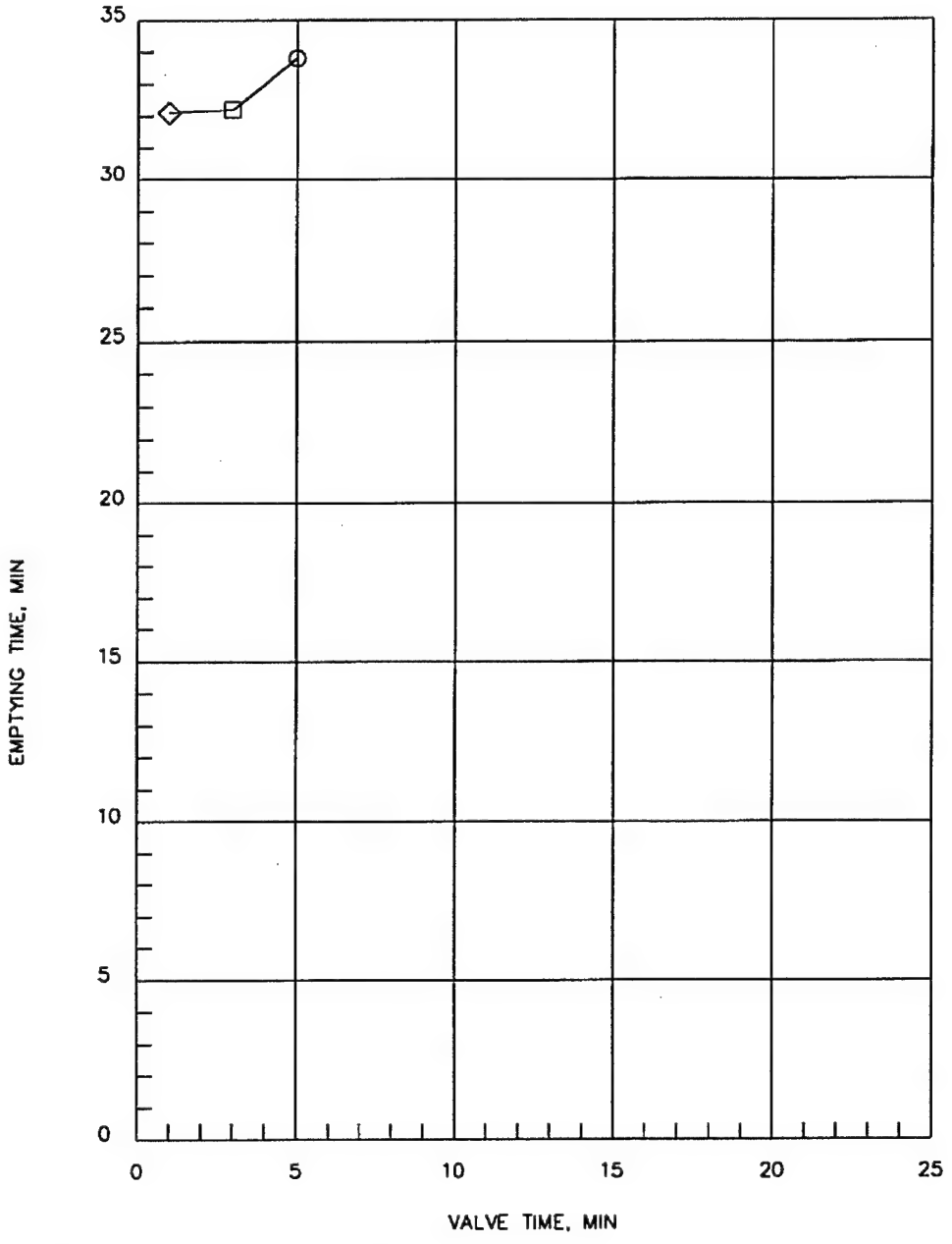




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
□	3
○	5

HAWSER FORCES
DURING EMPTYING
TYPE 5 DESIGN
15-ft Lift

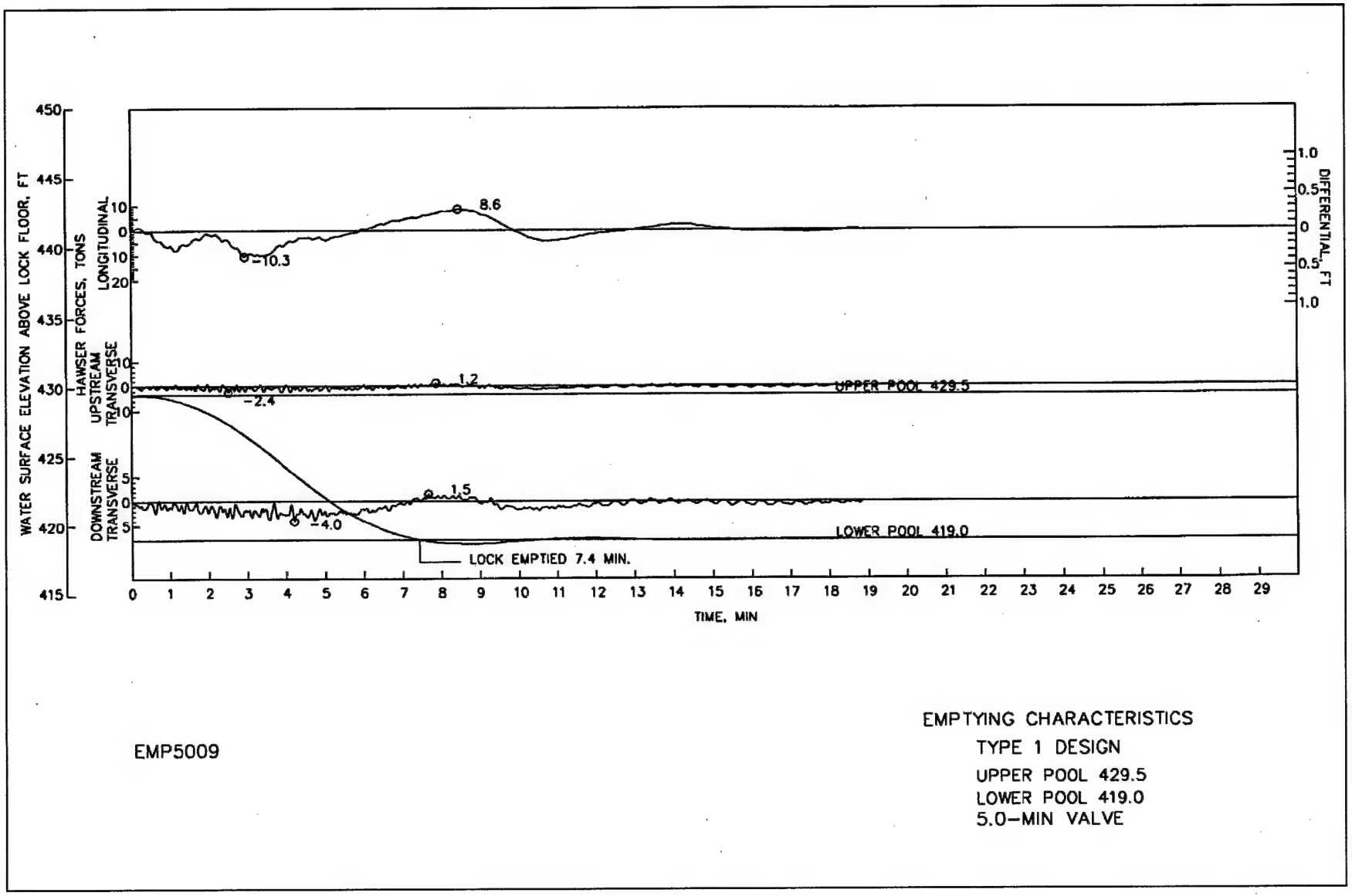
Plate 23



LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
□	3
○	5

OPERATION TIMES
DURING EMPTYING
TYPE 5 DESIGN
15–ft Lift

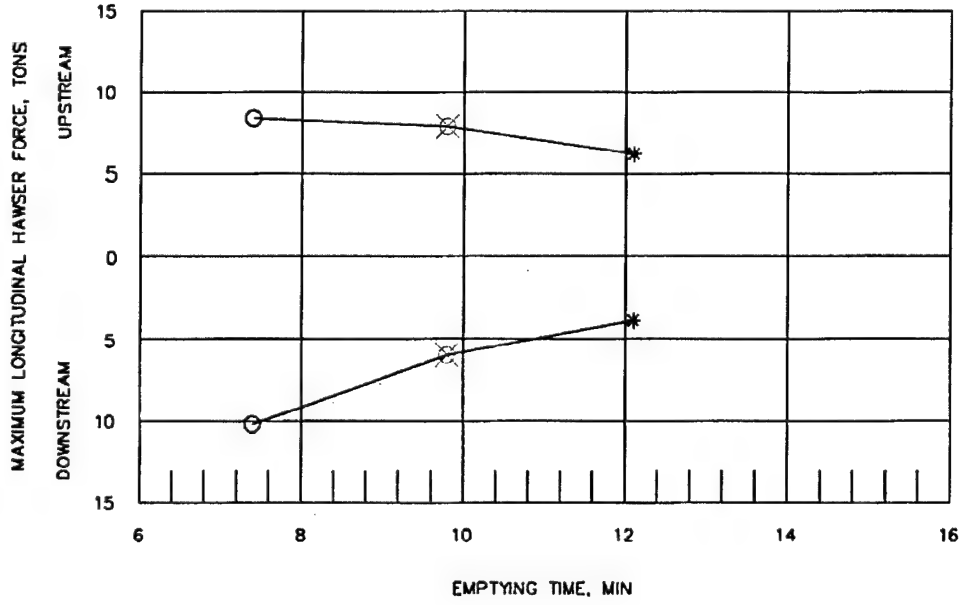
Plate 24

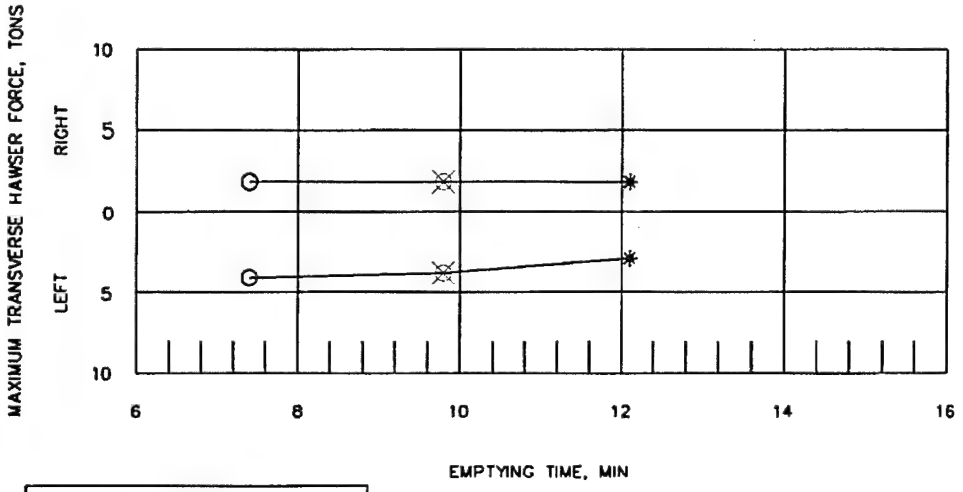


EMP5009

EMPTYING CHARACTERISTICS
TYPE 1 DESIGN
UPPER POOL 429.5
LOWER POOL 419.0
5.0–MIN VALVE

Plate 25

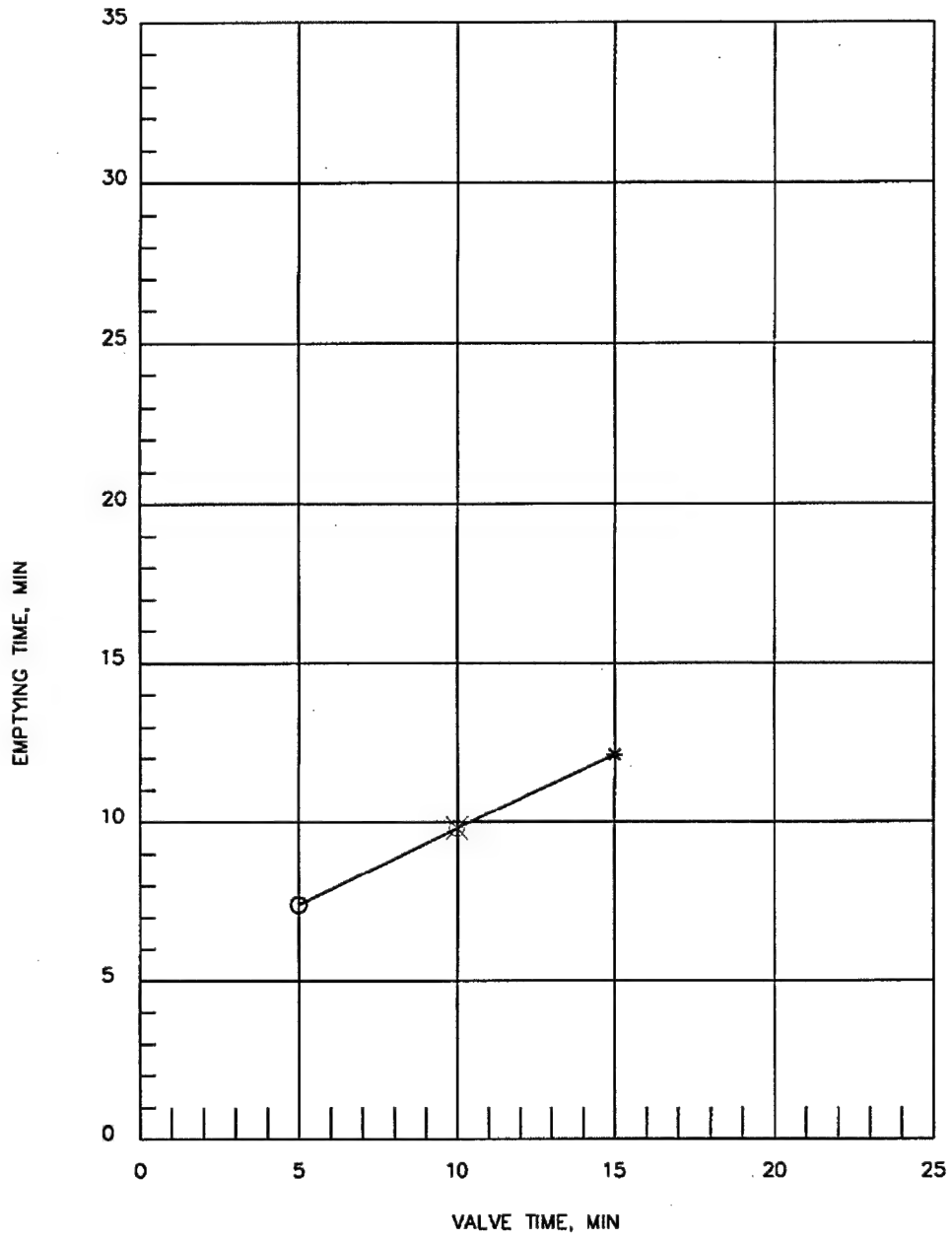




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	5
⊗	10
✳	15

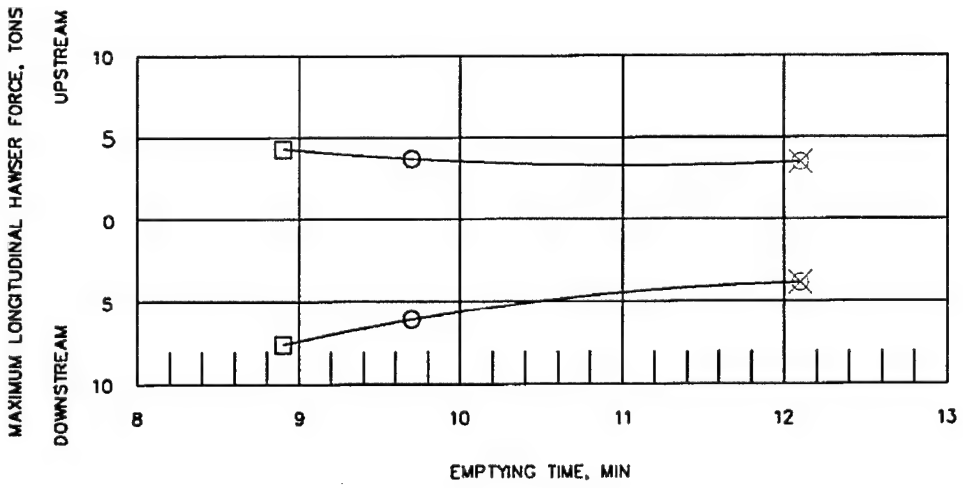
HAWSER FORCES
DURING EMPTYING
TYPE 1 DESIGN
10.5–ft Lift

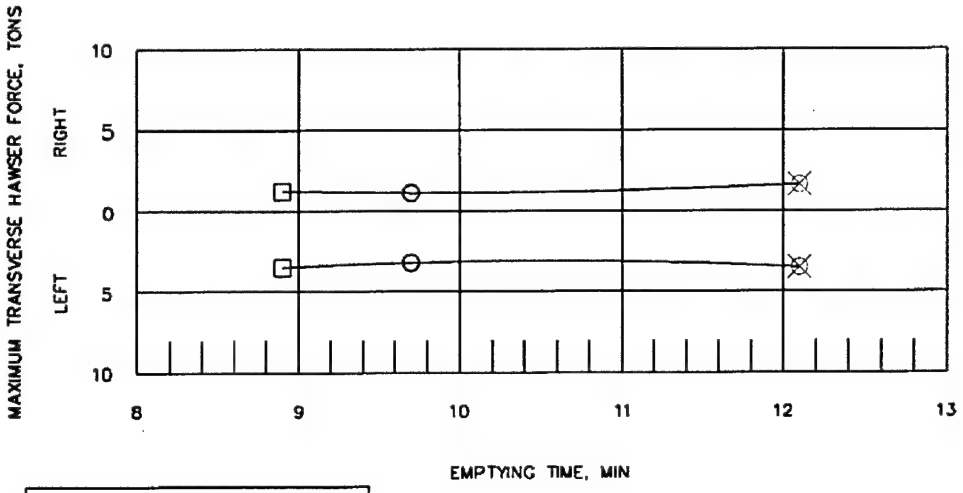
Plate 26



LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	5
⊠	10
✳	15

OPERATION TIMES
DURING EMPTYING
TYPE 1 DESIGN
10.5–ft Lift

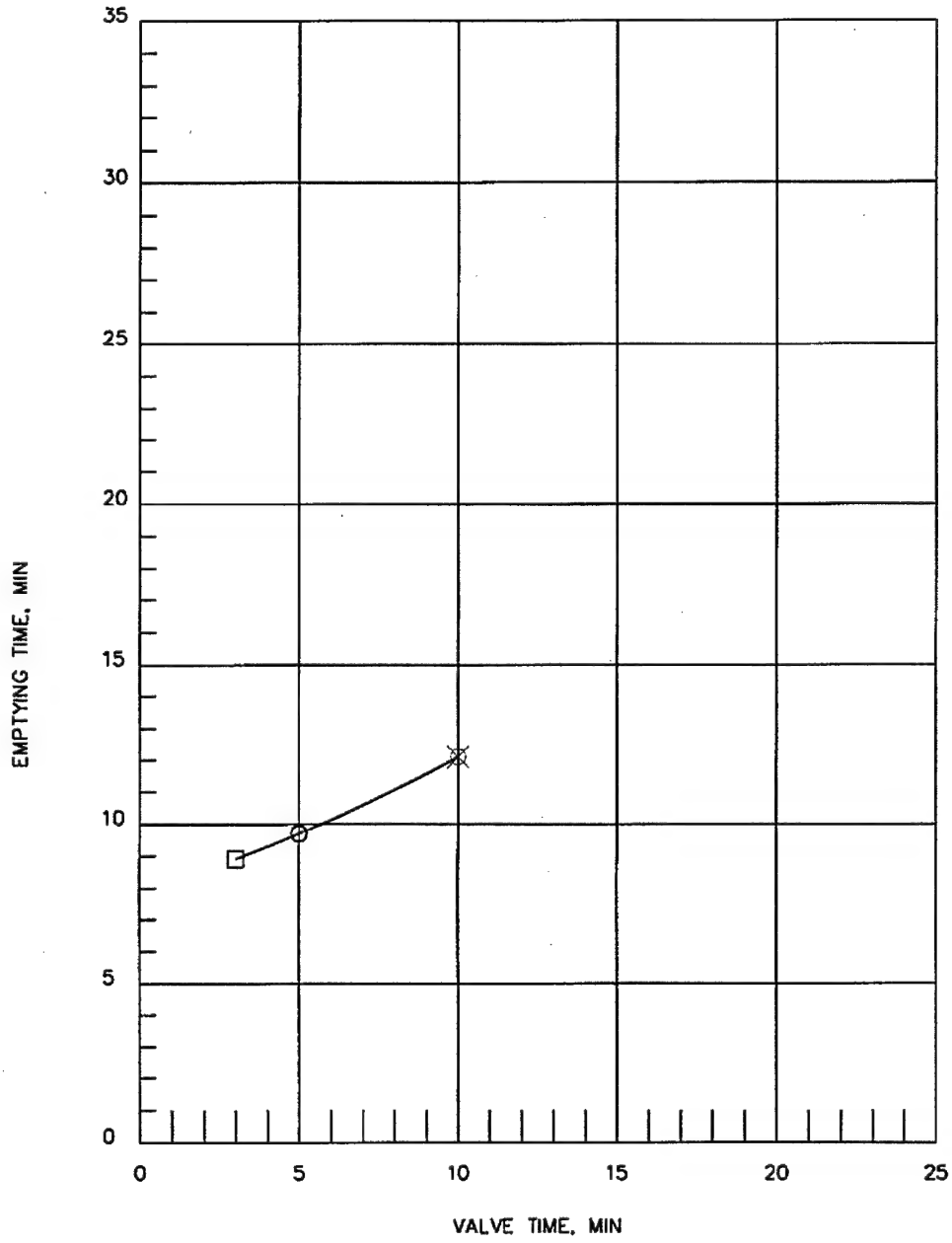




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
□	3
○	5
⊘	10

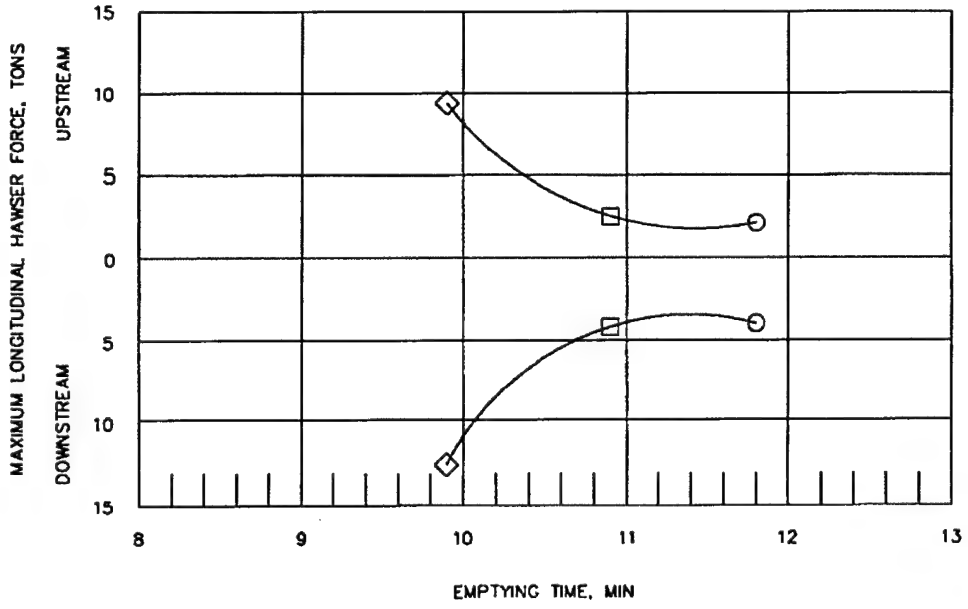
HAWSER FORCES
DURING EMPTYING
TYPE 2 DESIGN
10.5–ft Lift

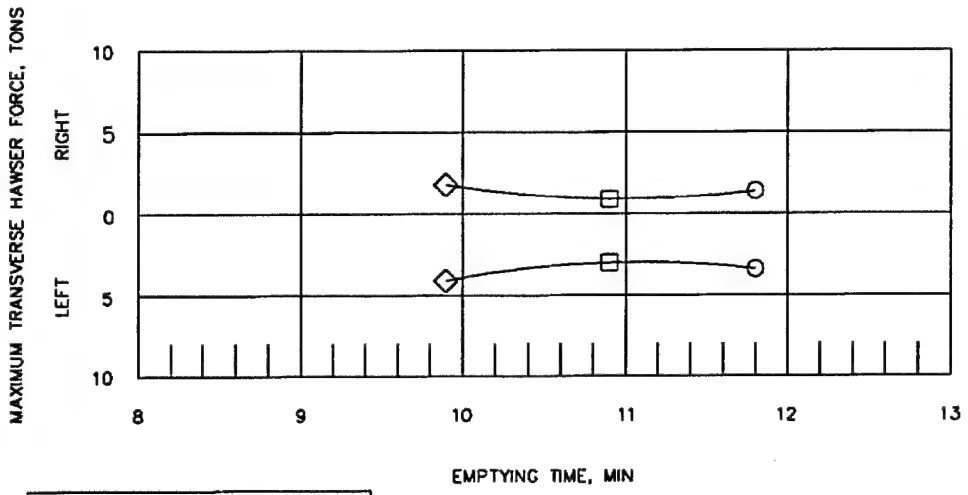
Plate 28



LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
□	3
○	5
⊗	10

OPERATION TIMES
DURING EMPTYING
TYPE 2 DESIGN
10.5–ft Lift

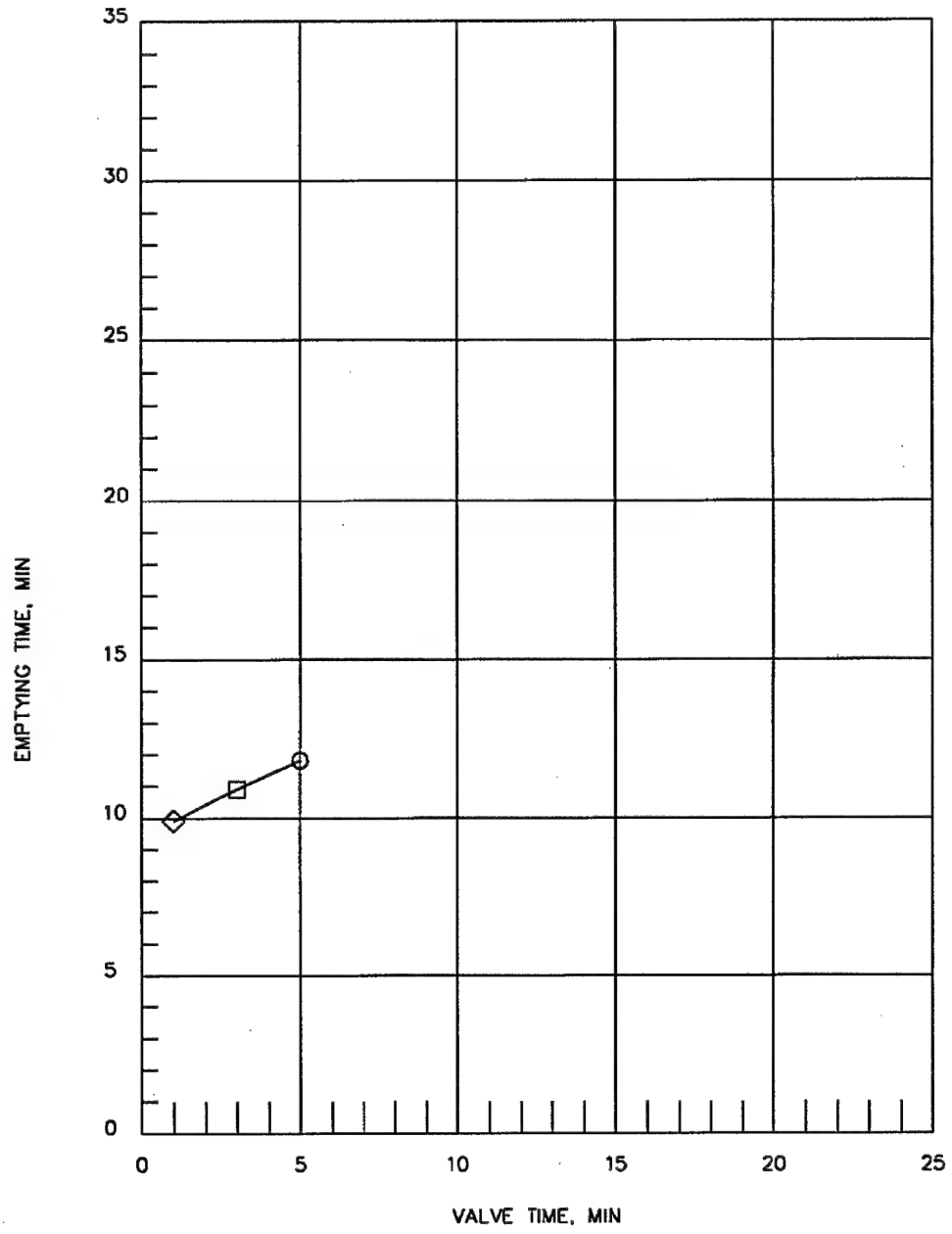




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
□	3
○	5

HAWSER FORCES
DURING EMPTYING
TYPE 3 DESIGN
10.5–ft Lift

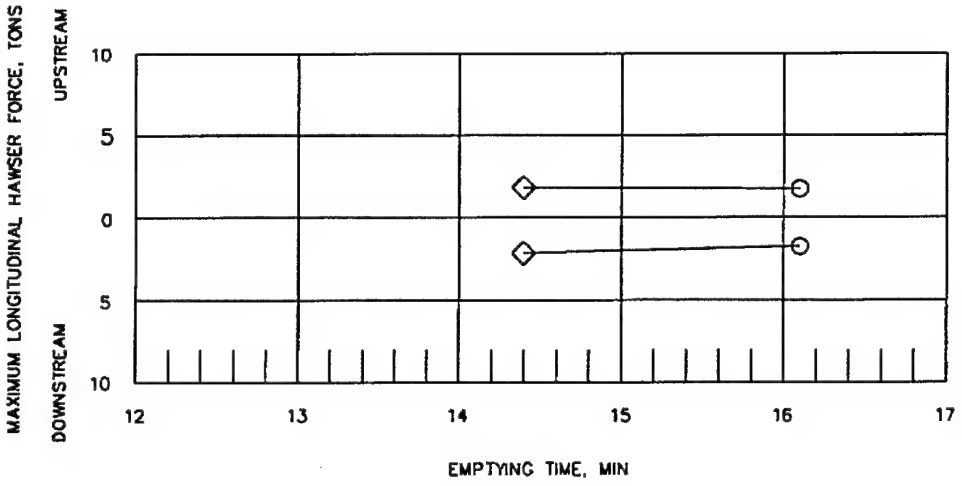
Plate 30

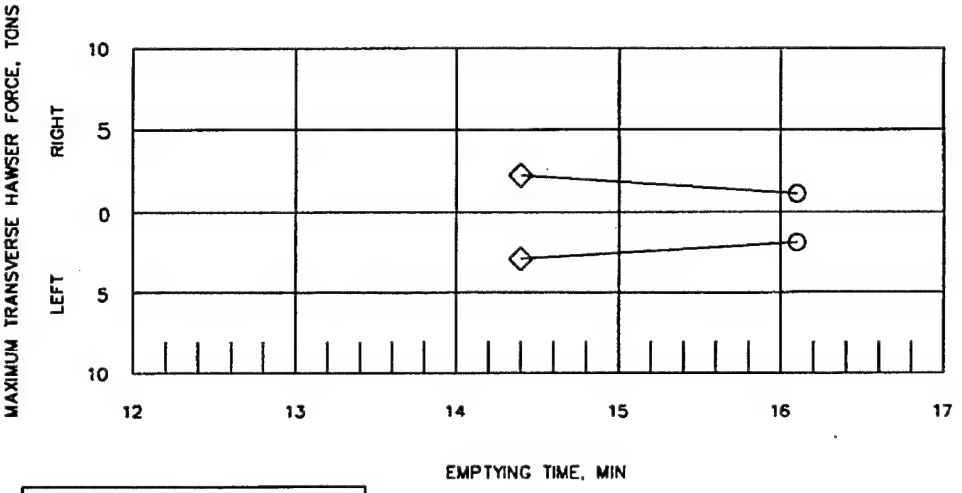


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
□	3
○	5

OPERATION TIMES
DURING EMPTYING
TYPE 3 DESIGN
10.5–ft Lift

Plate 31

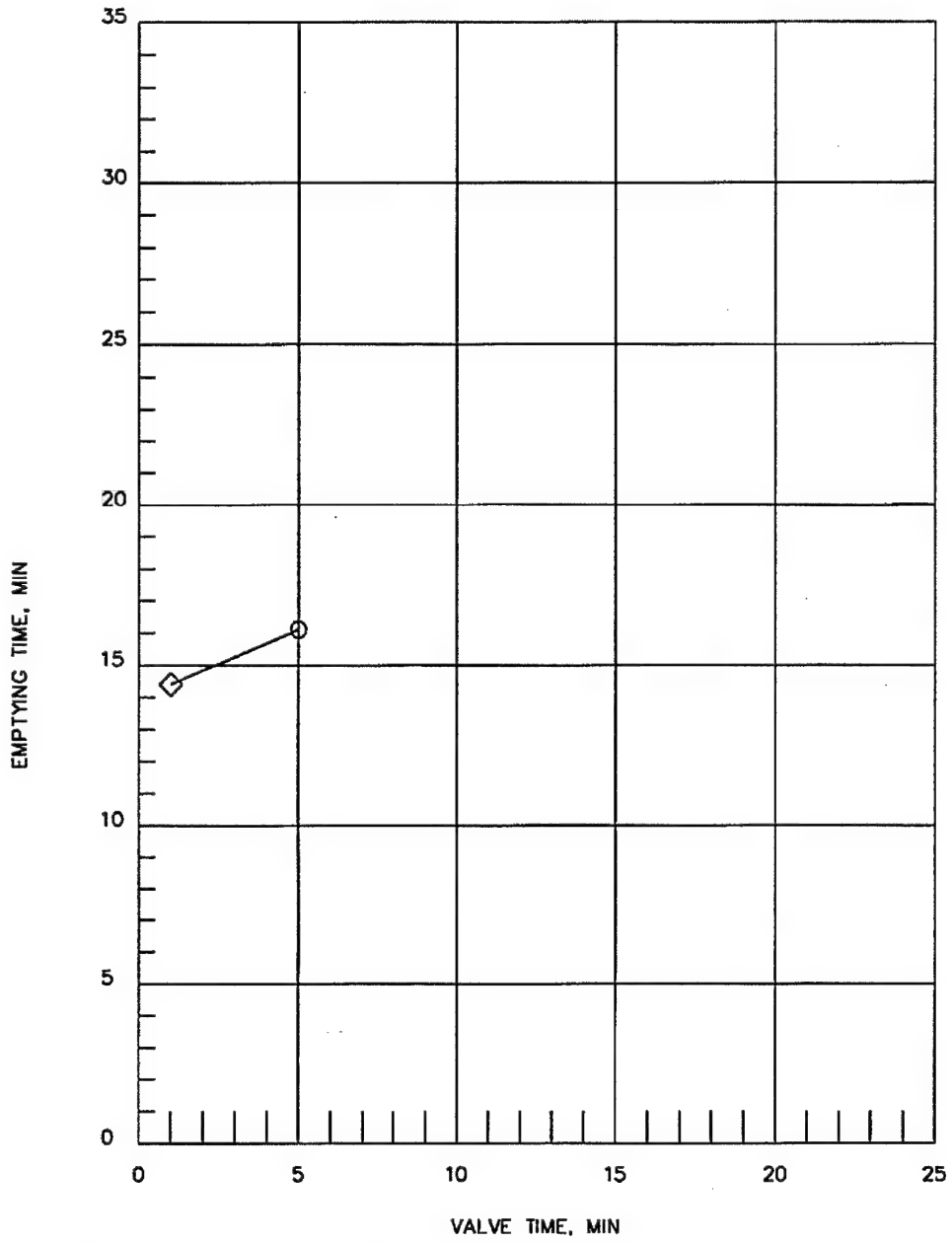




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
○	5

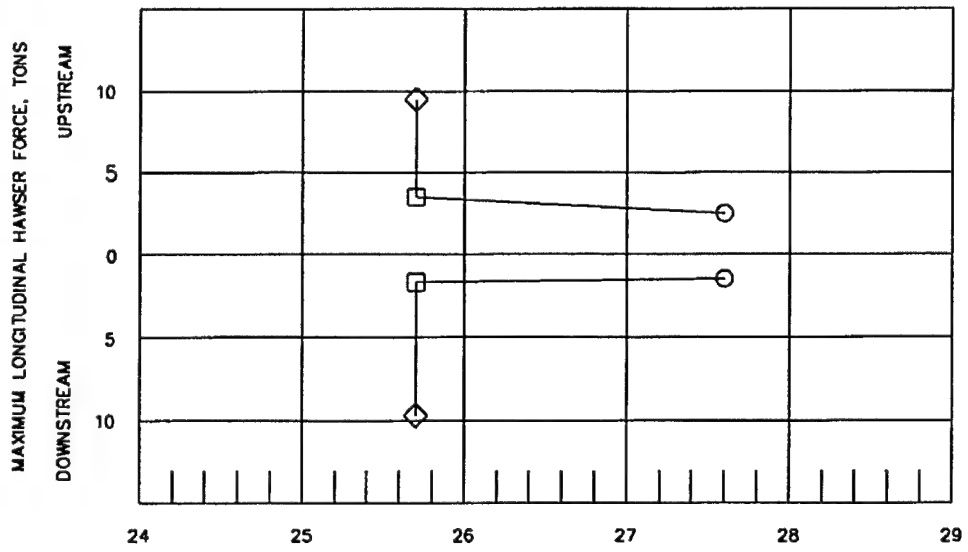
HAWSER FORCES
DURING EMPTYING
TYPE 4 DESIGN
10.5–ft Lift

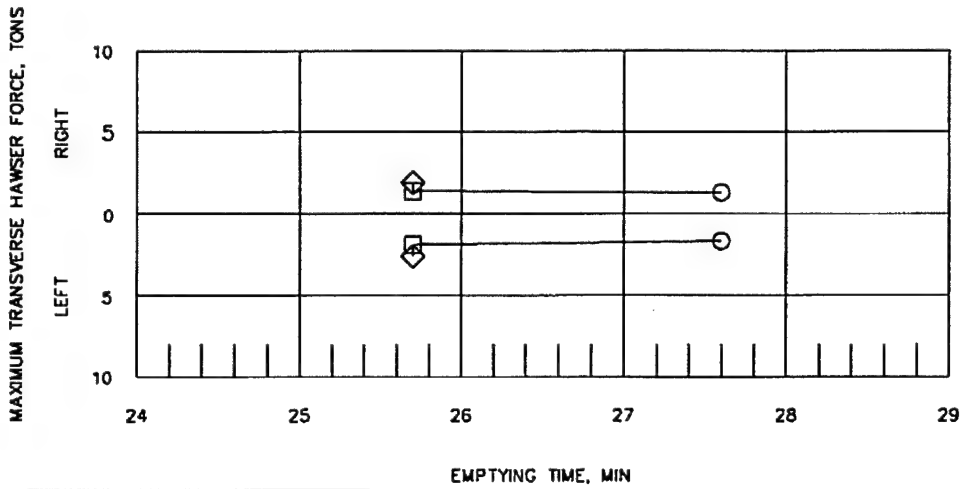
Plate 32



LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
○	5

OPERATION TIMES
DURING EMPTYING
TYPE 4 DESIGN
10.5–ft Lift

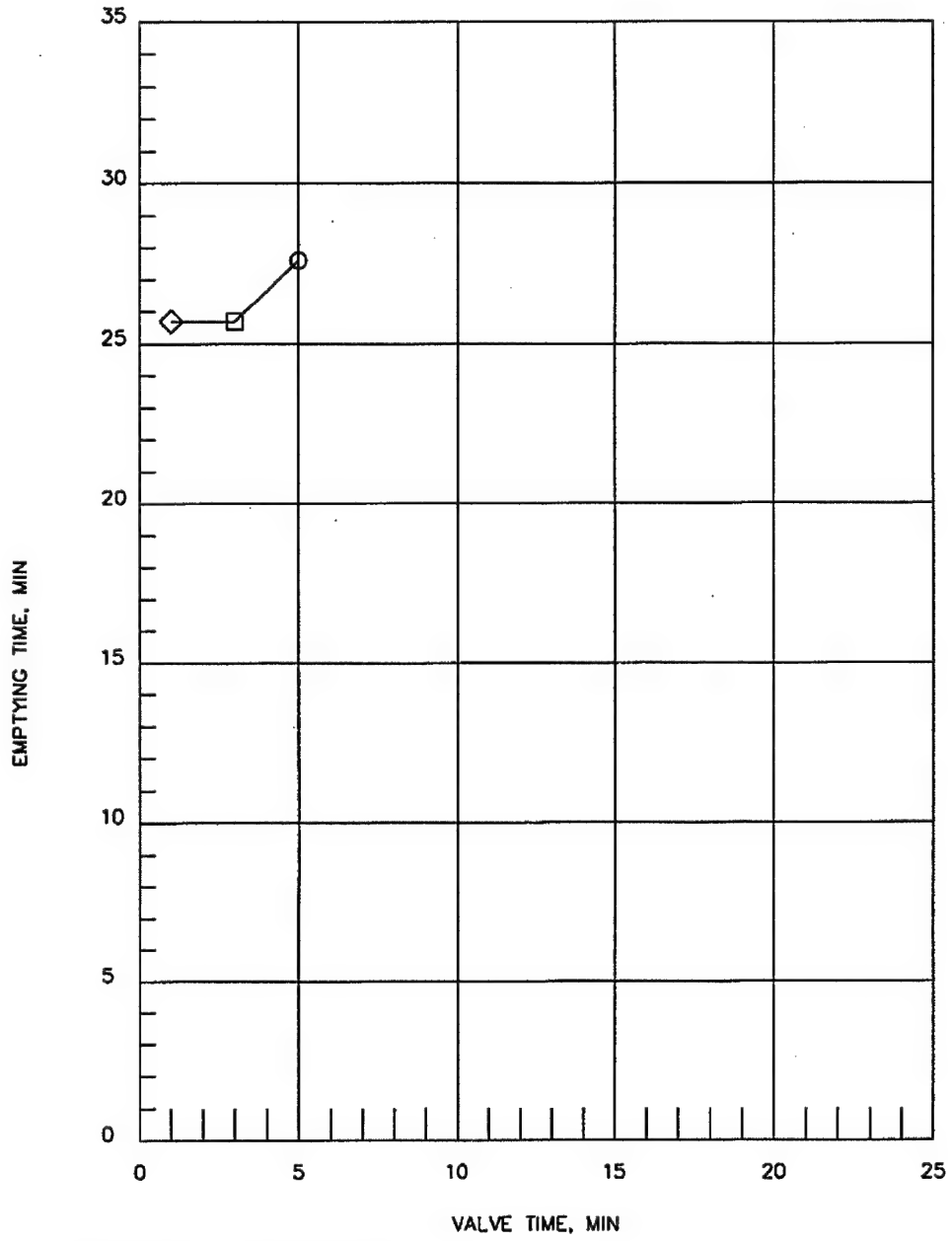




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
□	3
○	5

HAWSER FORCES
DURING EMPTYING
TYPE 5 DESIGN
10.5–ft Lift

Plate 34

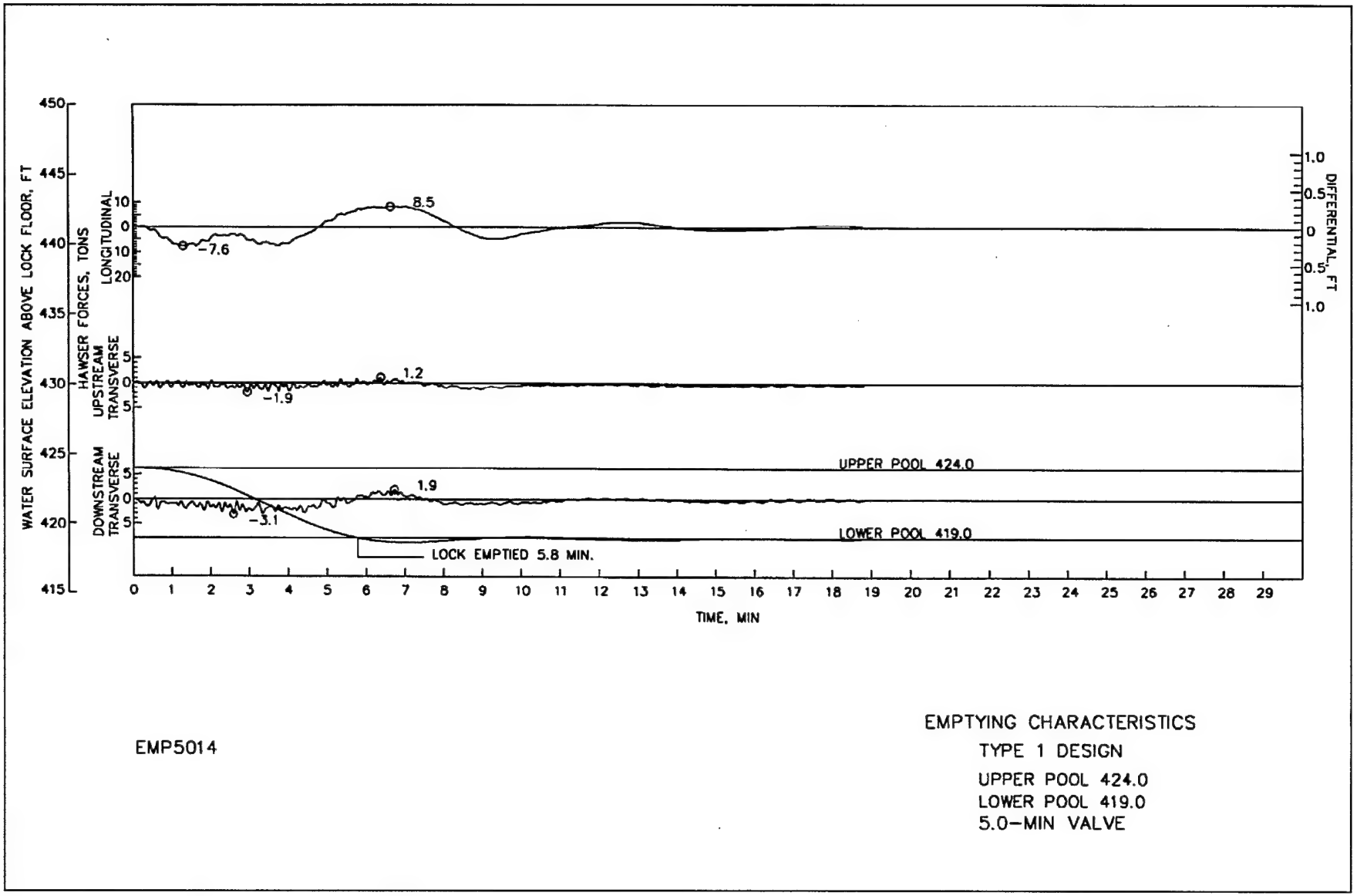


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
□	3
○	5

OPERATION TIMES
DURING EMPTYING
TYPE 5 DESIGN
10.5–ft Lift

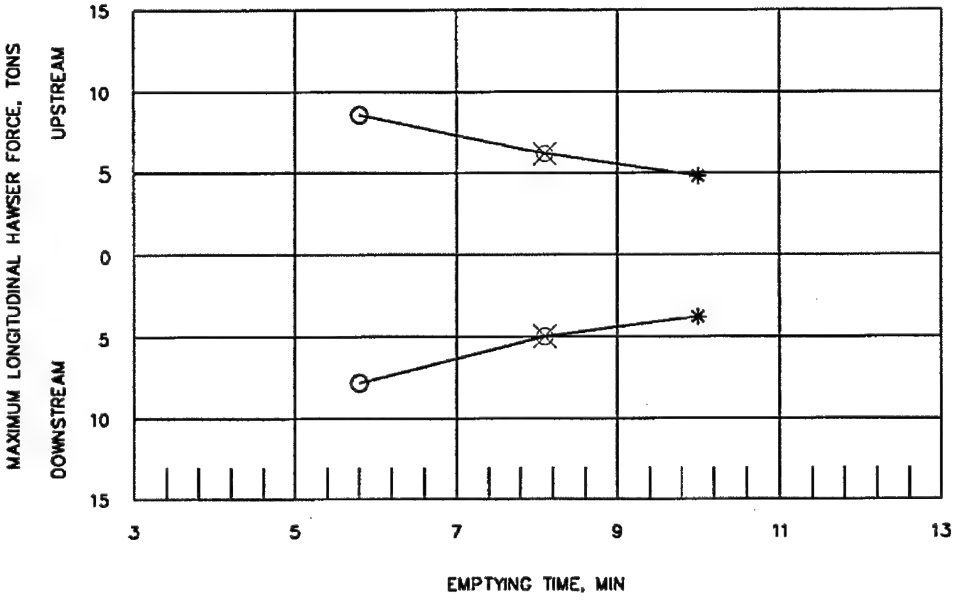
Plate 35

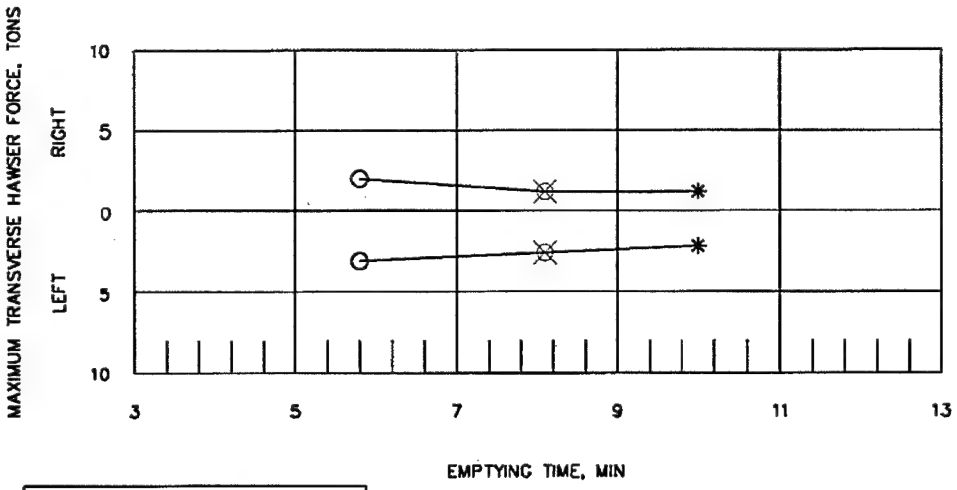
Plate 36



EMP5014

EMPTYING CHARACTERISTICS
TYPE 1 DESIGN
UPPER POOL 424.0
LOWER POOL 419.0
5.0–MIN VALVE

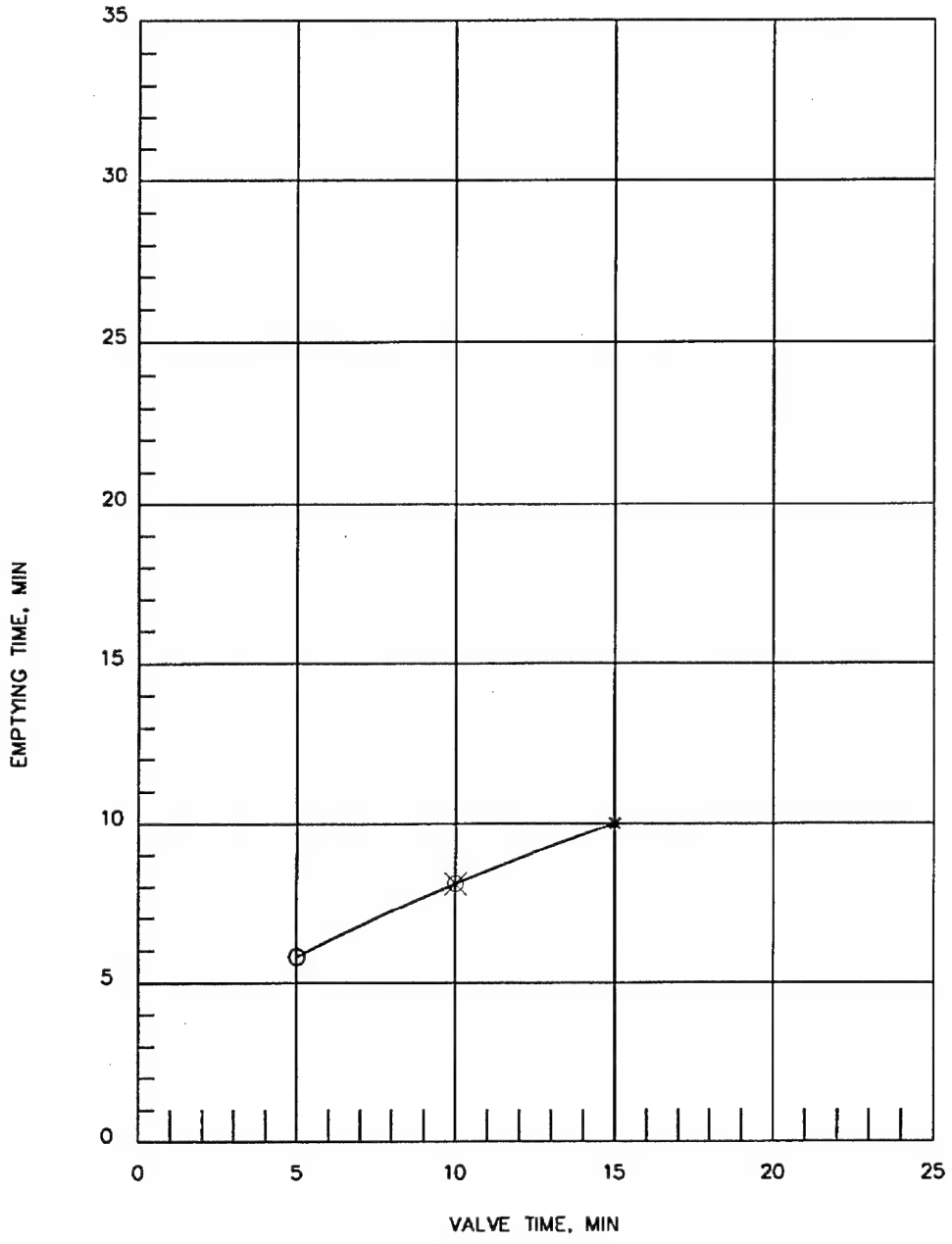




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	5
⊠	10
✱	15

HAWSER FORCES
DURING EMPTYING
TYPE 1 DESIGN
5–ft Lift

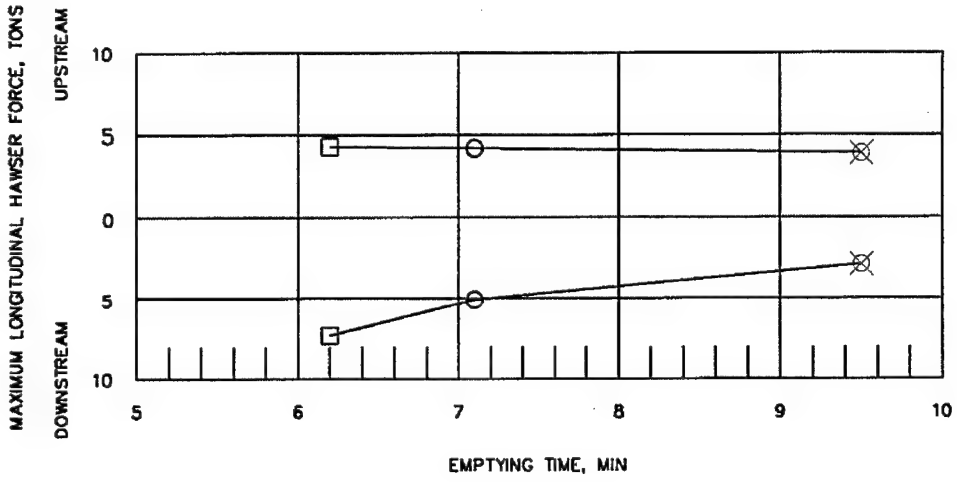
Plate 37

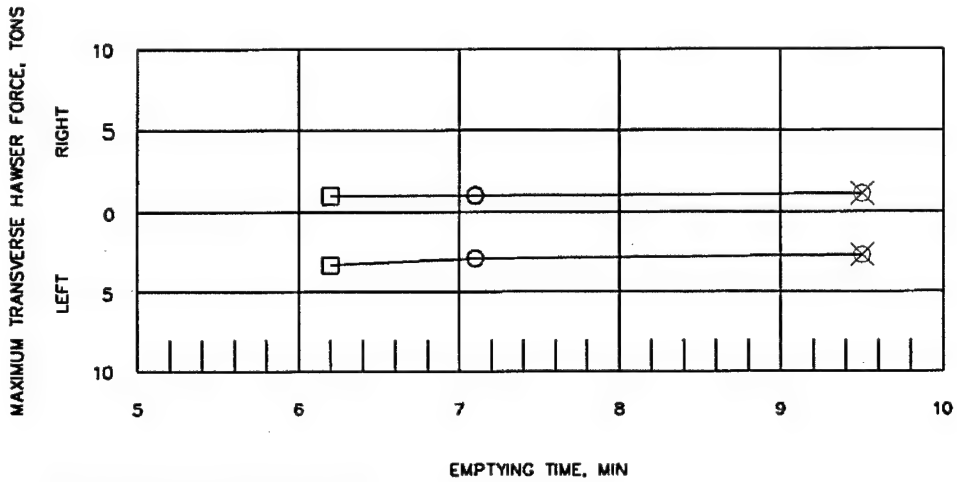


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	5
⊗	10
*	15

OPERATION TIMES
DURING EMPTYING
TYPE 1 DESIGN
5–ft Lift

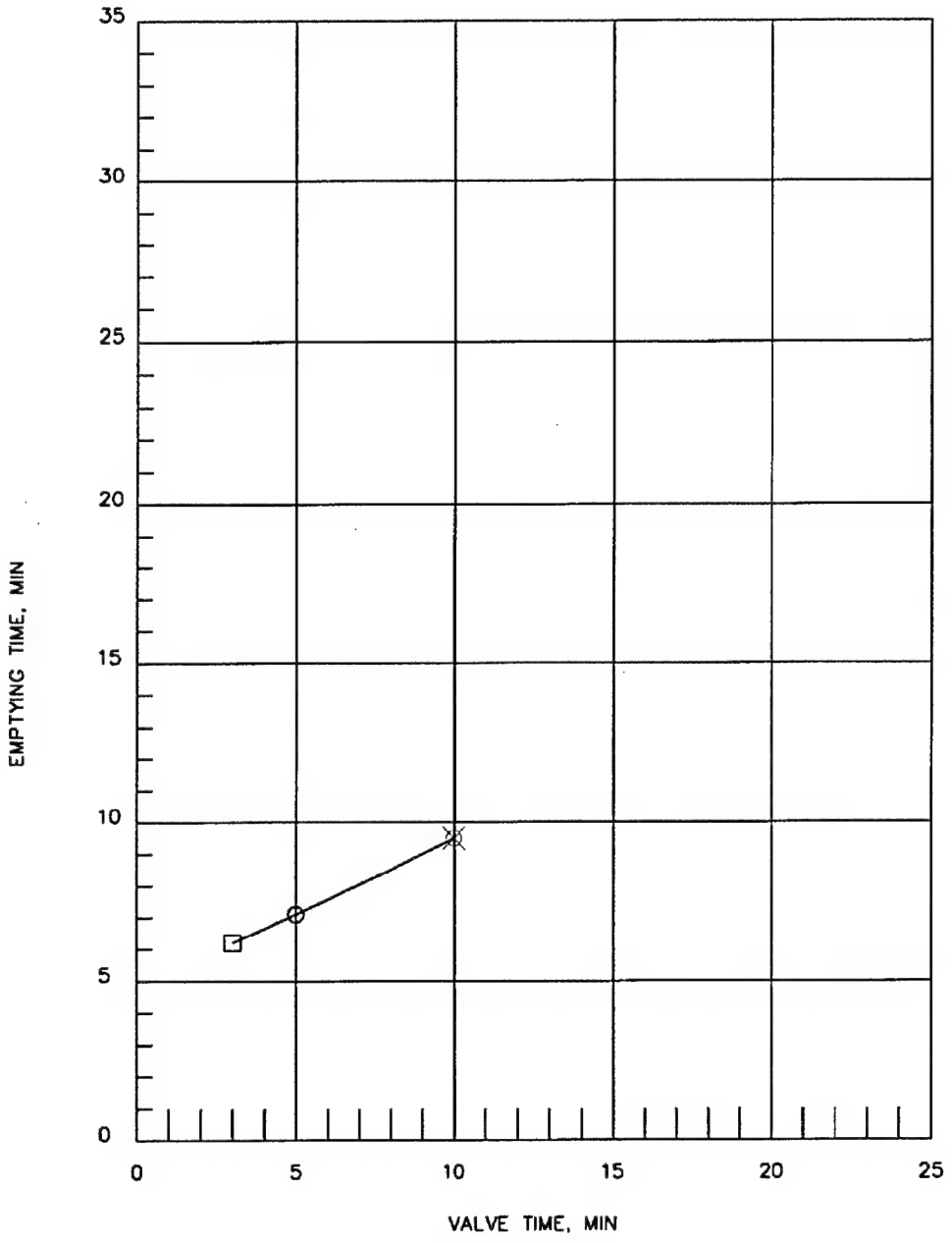
Plate 38





LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
□	3
○	5
⊗	10

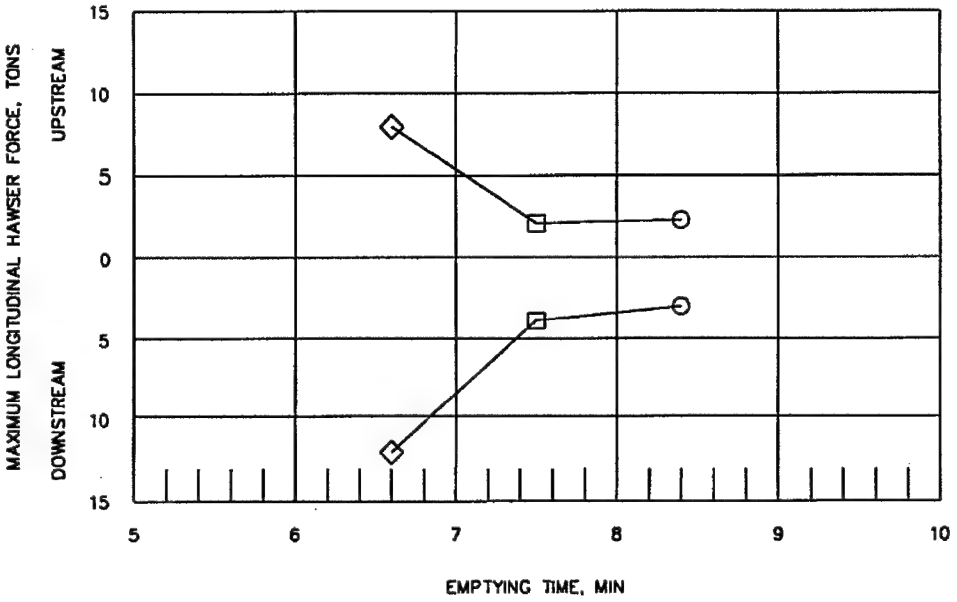
HAWSER FORCES
DURING EMPTYING
TYPE 2 DESIGN
5–ft Lift

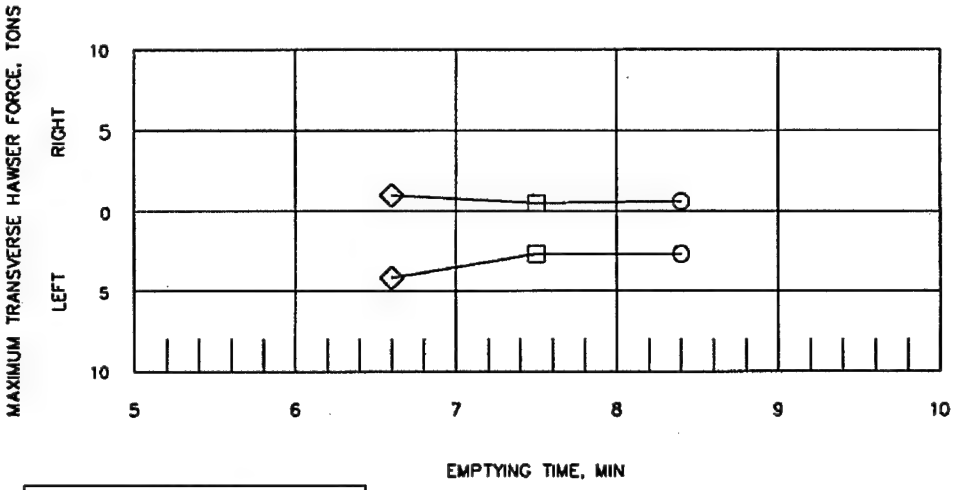


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
□	3
○	5
⊠	10

OPERATION TIMES
DURING EMPTYING
TYPE 2 DESIGN
5–ft Lift

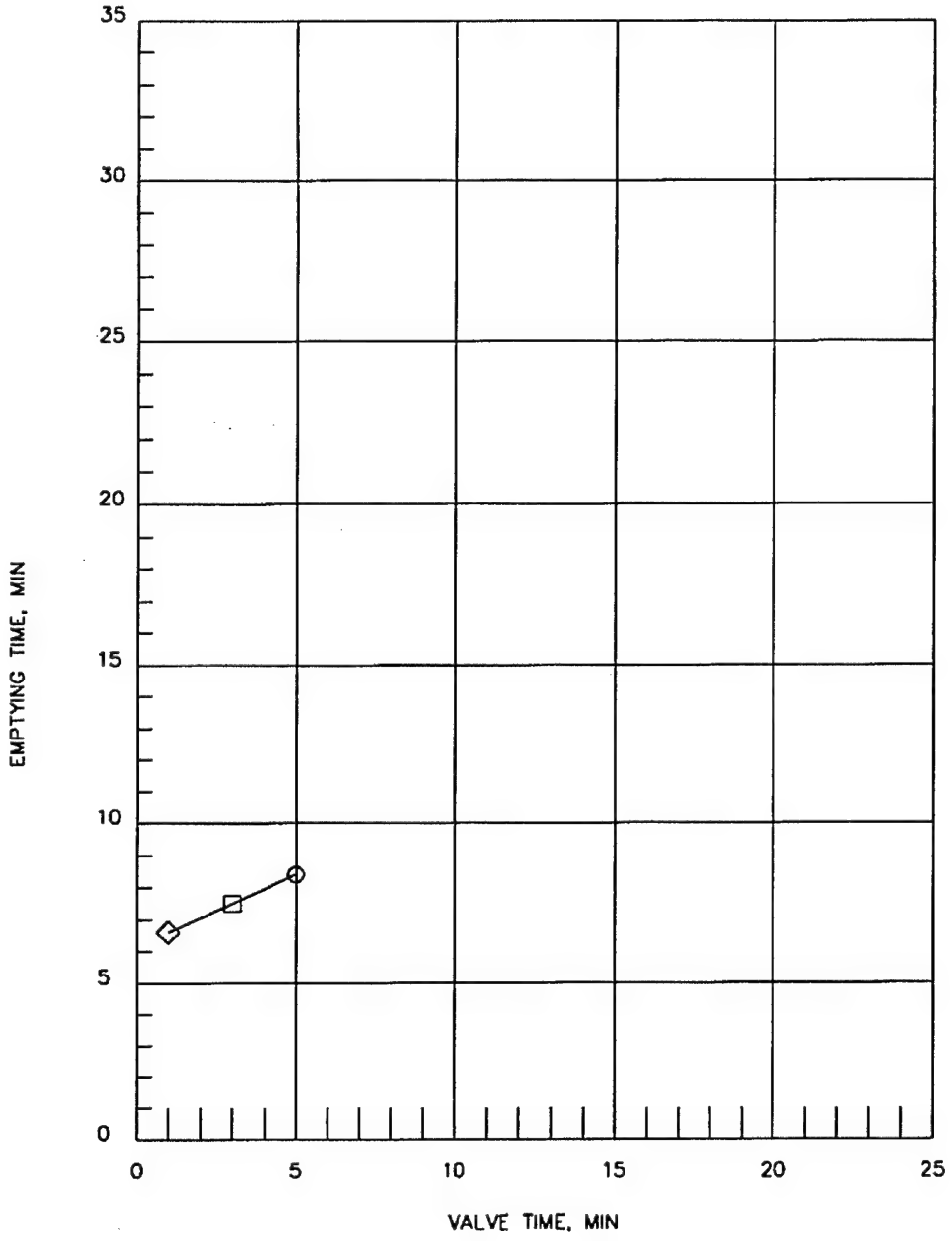
Plate 40





LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
□	3
○	5

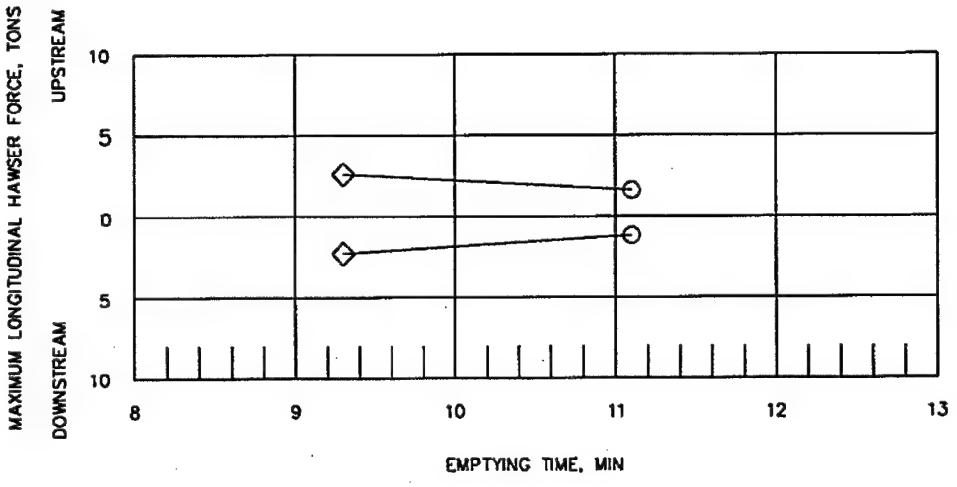
HAWSER FORCES
DURING EMPTYING
TYPE 3 DESIGN
5-ft Lift

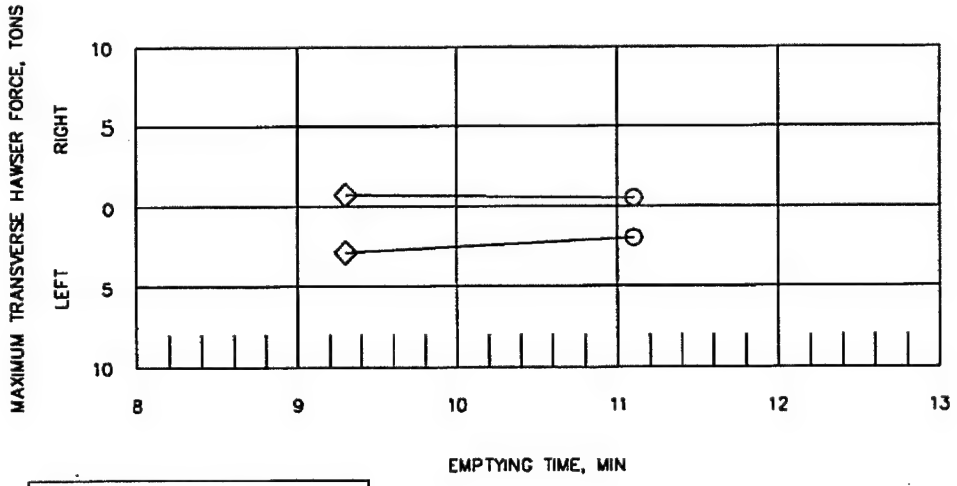


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
□	3
○	5

OPERATION TIMES
DURING EMPTYING
TYPE 3 DESIGN
5–ft Lift

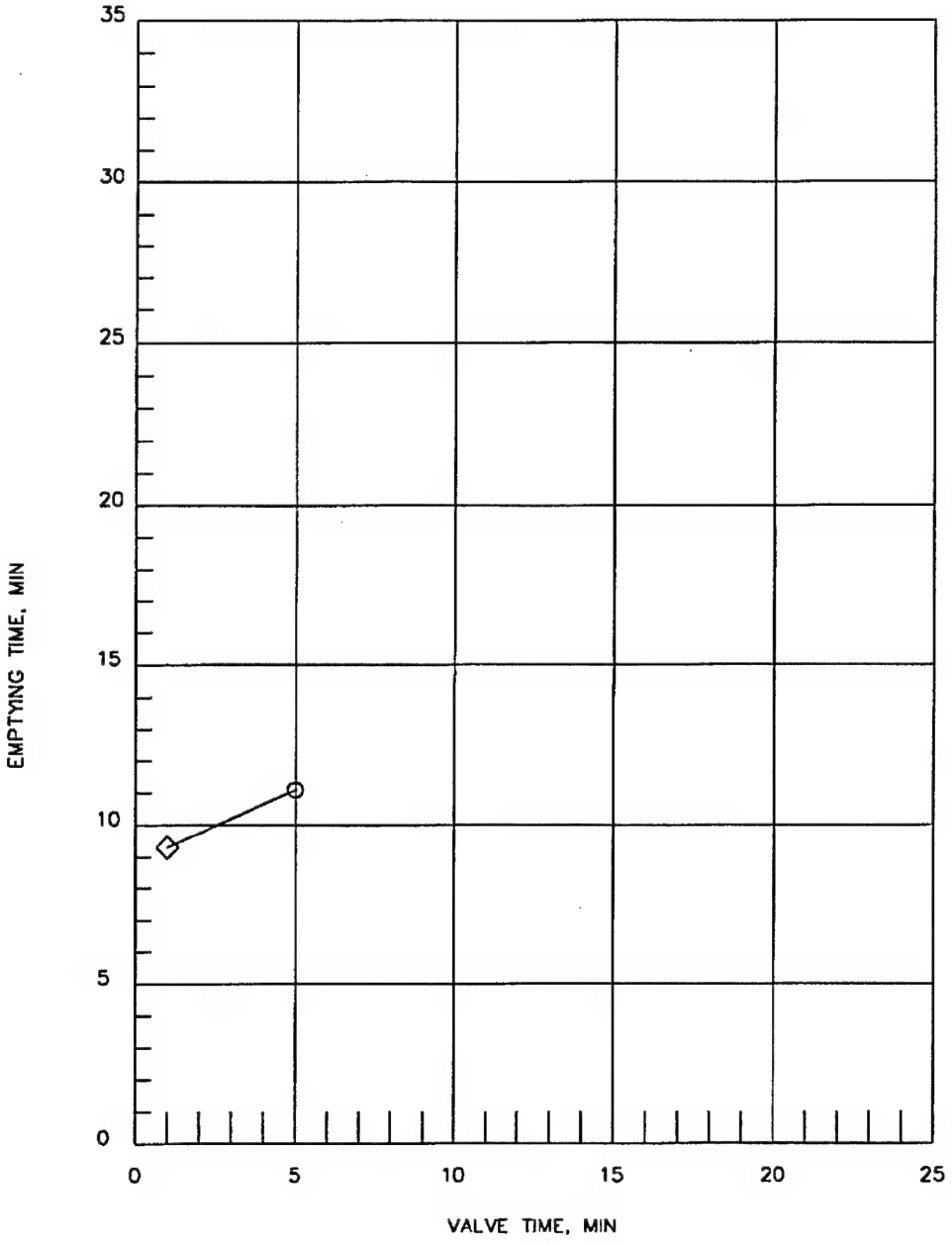
Plate 42





LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
○	5

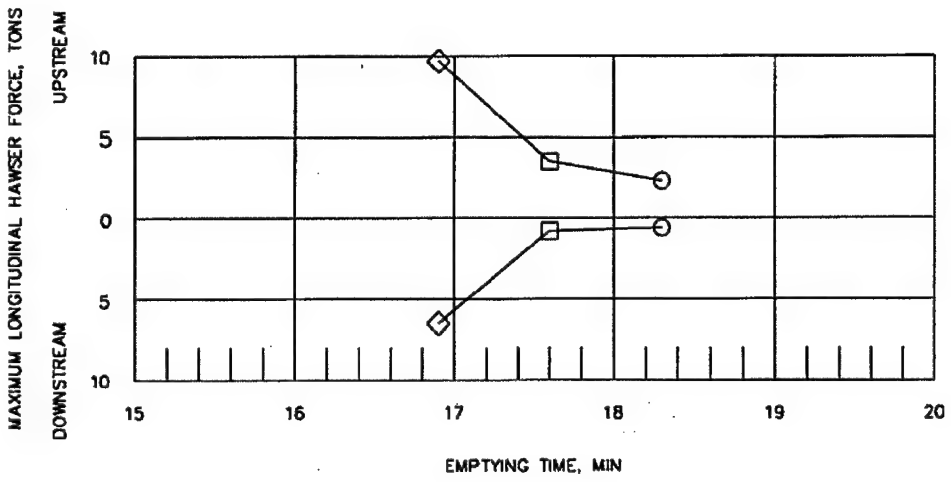
HAWSER FORCES
DURING EMPTYING
TYPE 4 DESIGN
5–ft Lift

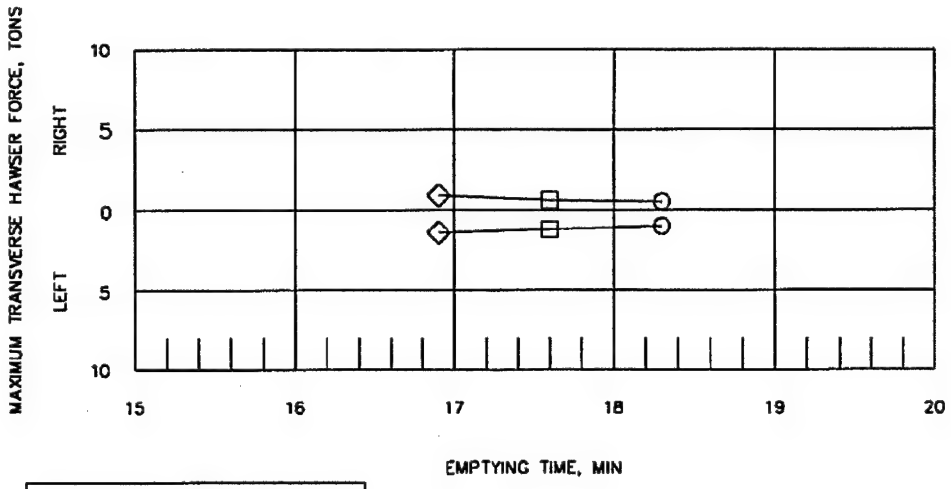


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
○	5

OPERATION TIMES
DURING EMPTYING
TYPE 4 DESIGN
5-ft Lift

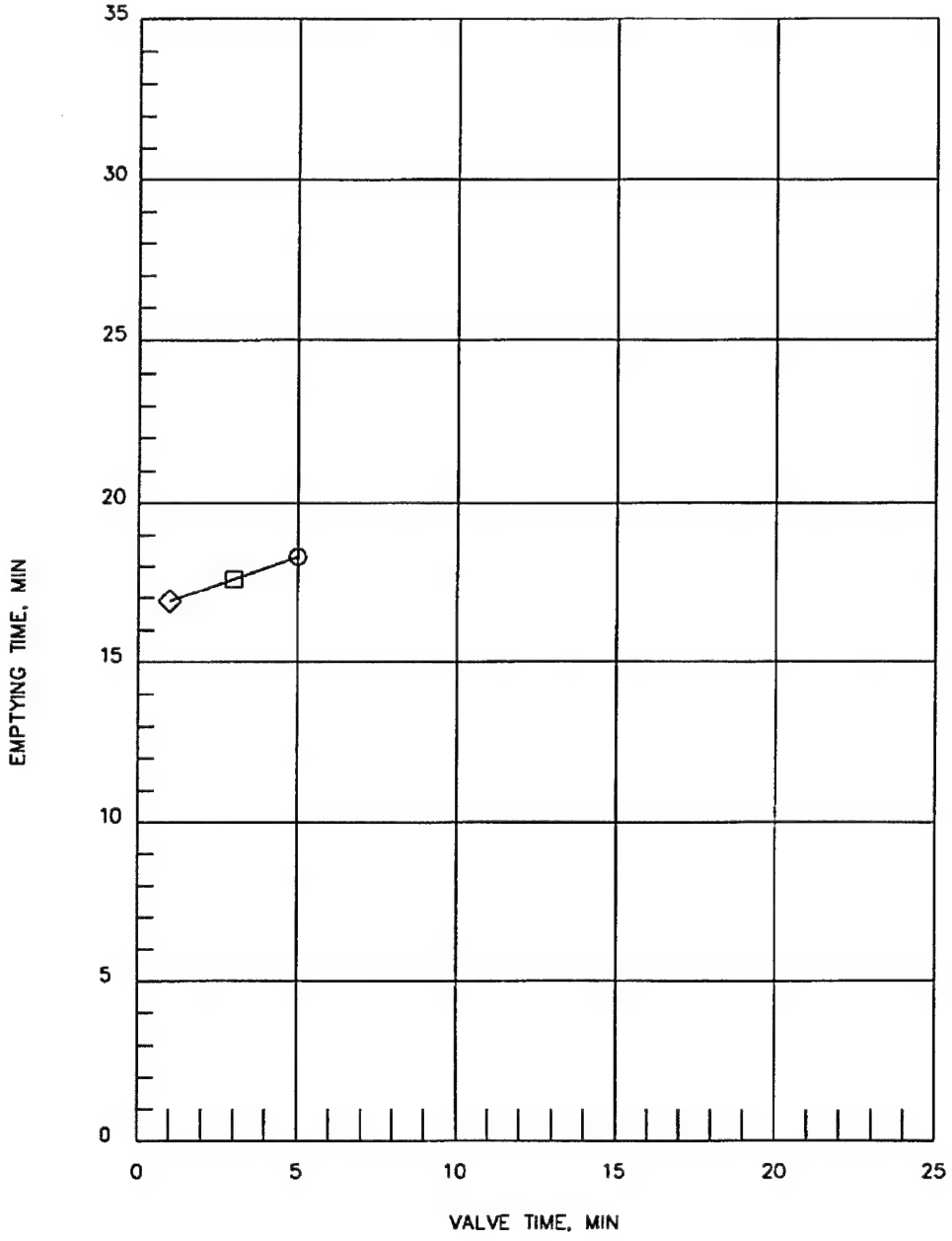
Plate 44





LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
□	3
○	5

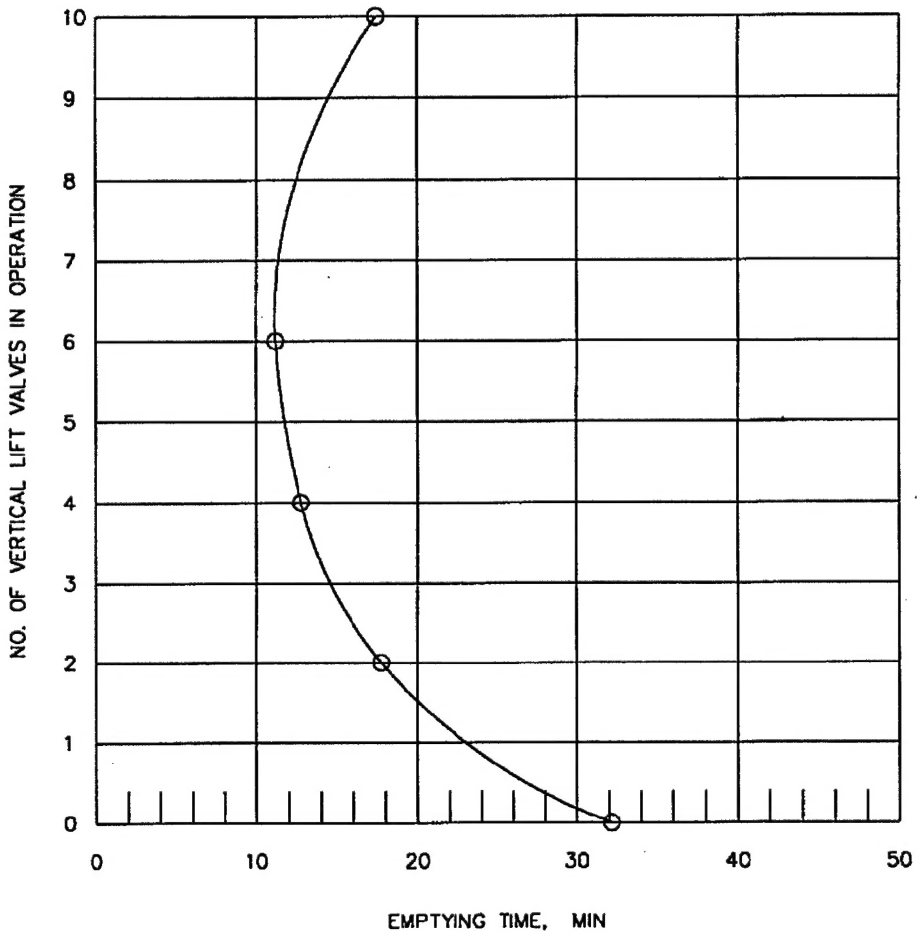
HAWSER FORCES
DURING EMPTYING
TYPE 5 DESIGN
5–ft Lift



LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
◇	1
□	3
○	5

OPERATION TIMES
DURING EMPTYING
TYPE 5 DESIGN
5–ft Lift

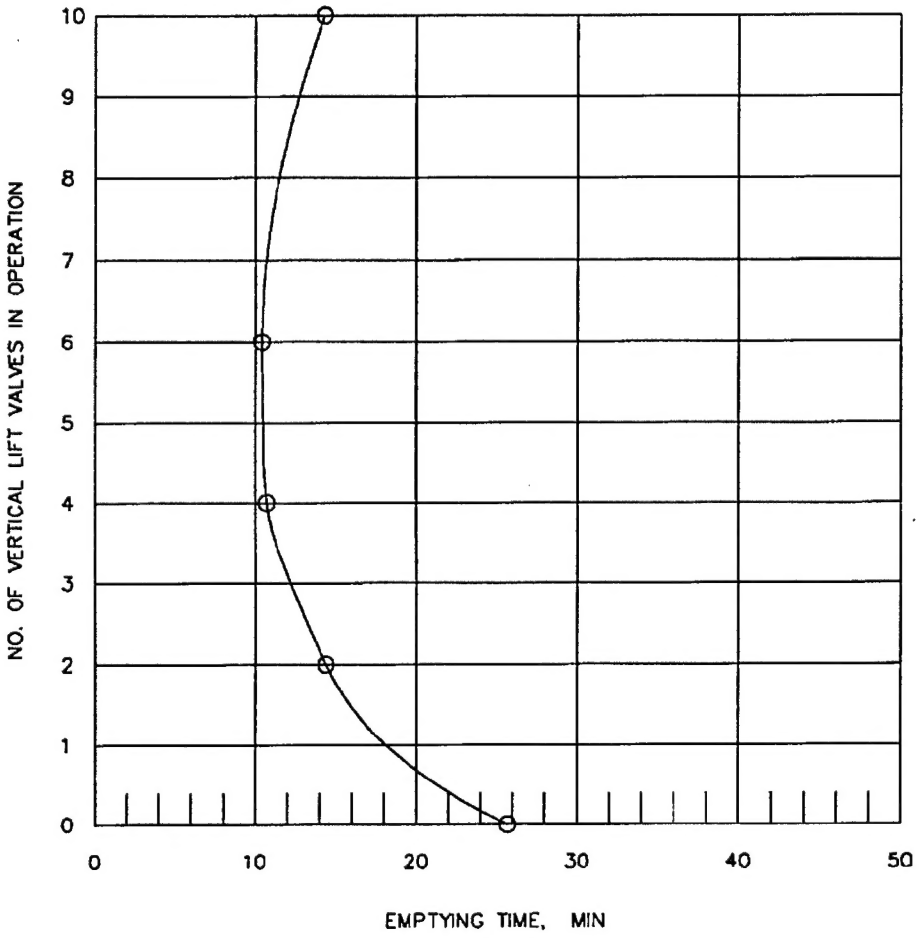
Plate 46



MINIMUM EMPTY TIME TO MAINTAIN
5–TON HAWSER FORCES OR LESS

TAINTER VALVE OPERATING
15–ft LIFT

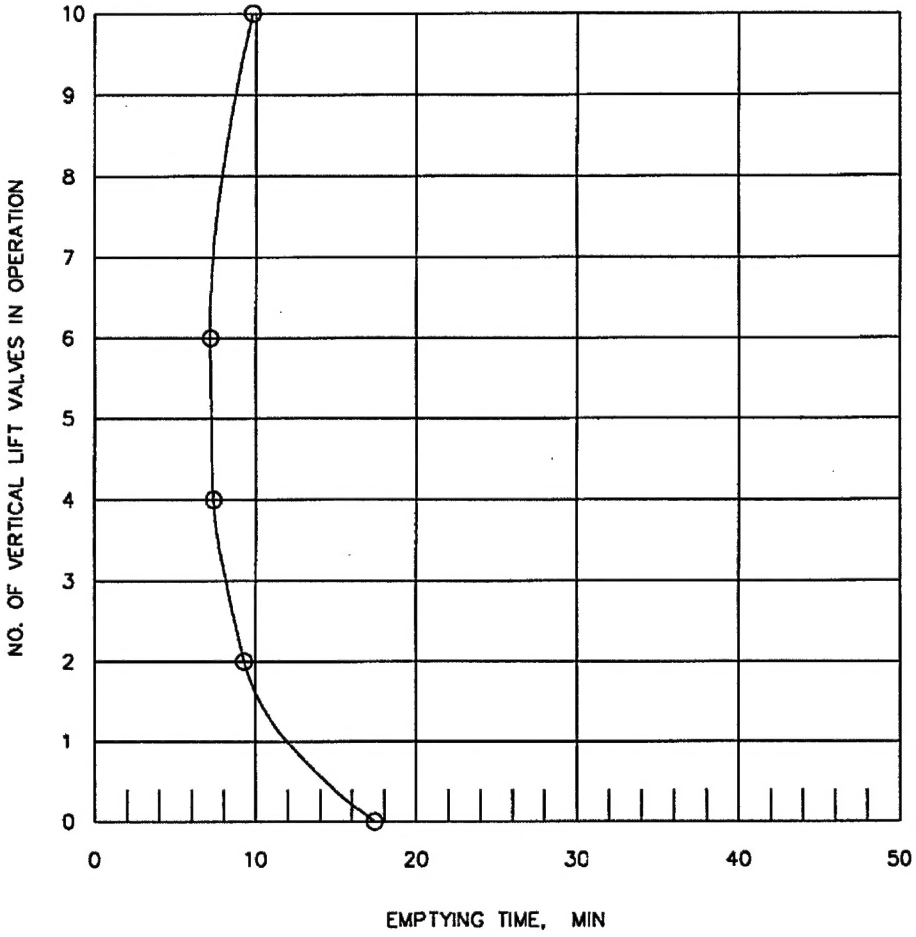
Plate 47



MINIMUM EMPTY TIME TO MAINTAIN
5-TON HAWSER FORCES OR LESS

TAINTER VALVE OPERATING
10.5-ft LIFT

Plate 48



MINIMUM EMPTY TIME TO MAINTAIN
5-TON HAWSER FORCES OR LESS

TAINTER VALVE OPERATING
5-ft LIFT

Plate 49

REPORT DOCUMENTATION PAGE

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5c. PROGRAM ELEMENT NUMBER

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Jose E. Sanchez, Mario J. Sanchez, John E. Hite, Jr.

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U.S. Army Engineer Research and Development Center
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Vicksburg, MS 39180-6199

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14. ABSTRACT

Navigation improvements including lock extensions are being investigated for several existing projects on the Upper Mississippi River (UMR). A hydraulic model study was conducted to evaluate filling and emptying system design alternatives for the extension of lock No. 22 and lock No. 25. A 1:25 scale model was constructed to determine the range of lock performance for both locks. The filling system flow capacity was not significantly changed from the original non-extended lock design. The filling time for acceptable chamber performance with the 4.57-m (15-ft) lift was 23.1 min. This filling time was achieved with a 23-min valve. The focus of the study was to determine emptying performance for multiple options of emptying gates built in the extended portion of the lock chamber river wall. Several emptying system designs were studied. The type 2 and 3 design provided the best chamber performance during the emptying operation.

15. SUBJECT TERMS

Hydraulic models
Lock and dam No. 22
Lock and dam No. 25
Lock design
Lock extension
Upper Mississippi River (UMR)

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